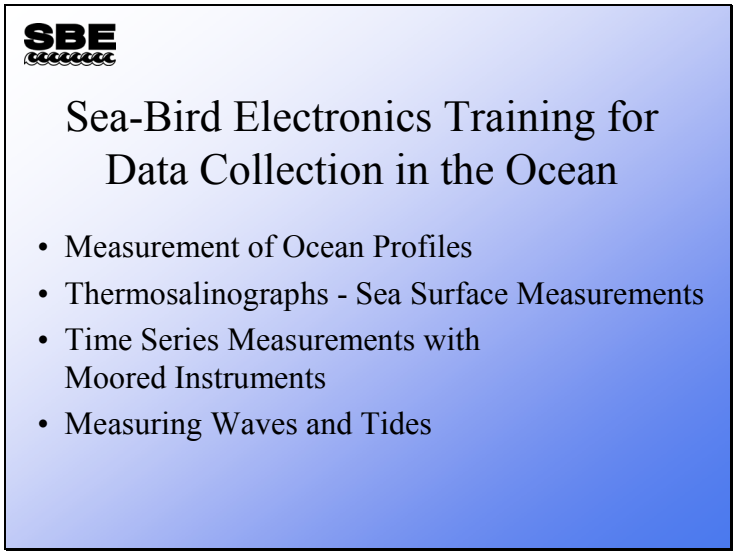
Module 0

Introduction to Sea-Bird Electronics Training for Data Collection in the Ocean

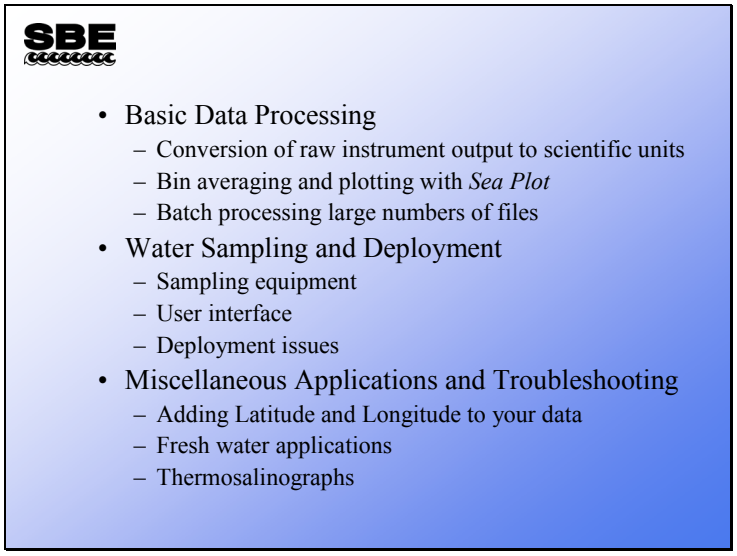
SBE Training Introduction



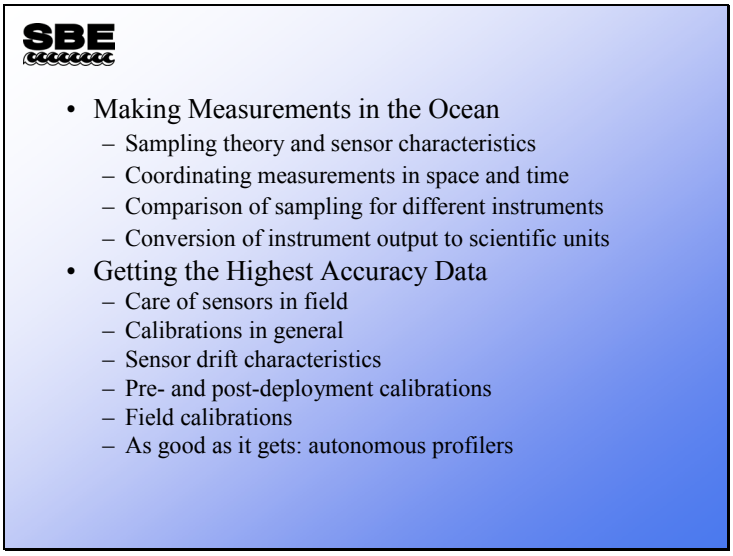
Welcome to Sea-Bird Electronics training course. The next few slides will show you what we are going to cover in a little more detail.

Topics We Will Cover

Topics We Will Cover (*continued*)



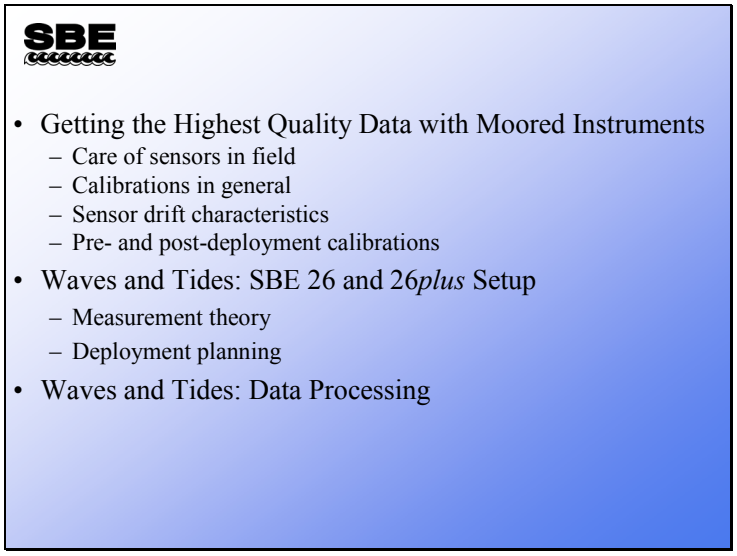
Topics We Will Cover (*continued*)



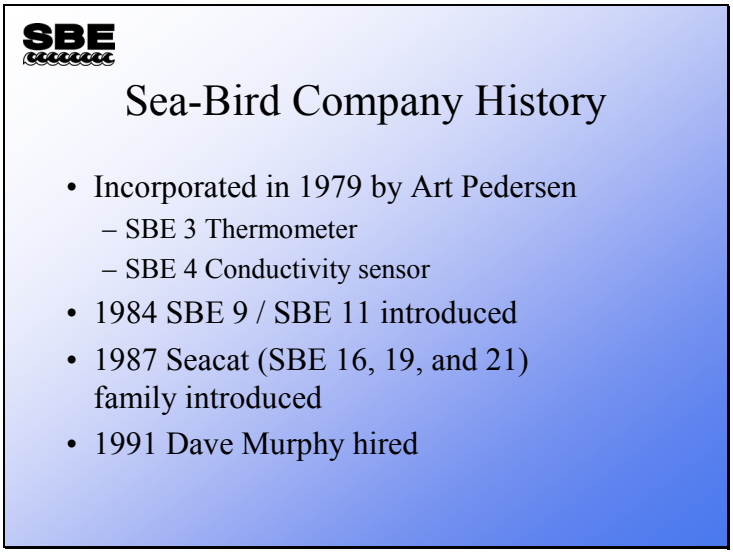
Topics We Will Cover (*continued*)

- Advanced Data Processing
  - Sensor alignment, matching measurements of same water parcel
  - Underwater package-induced errors
  - Correcting for conductivity cell thermal mass
  - Data editing and filtering
- Moored Instruments
  - SBE 16 and SBE 16*plus*
  - SBE 37
  - SBE 39
  - Inductive modem telemetry
- Setup of Moored Instruments
  - Preparation for deployment

Topics We Will Cover (*continued*)

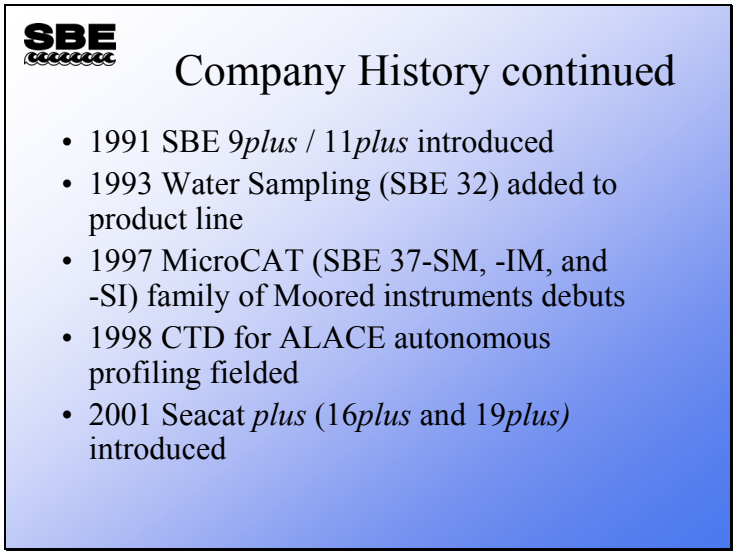


Sea-Bird Electronics Company History



Art Pederson developed Sea-Bird's first products for an autonomous vehicle at the University of Washington's Applied Physics Laboratory in 1961. These first products later became the SBE 3 ocean thermometer and SBE 4 conductivity sensor. Pederson incorporated Sea-Bird Electronics in 1979 with these two sensor products. From there, the product line expanded to include real-time ocean profiling instruments with the SBE 9 / SBE 11 acquisition/telemetry equipment and stored data profiling instruments with the Seacat product line.

Sea-Bird Electronics Company History (*continued*)

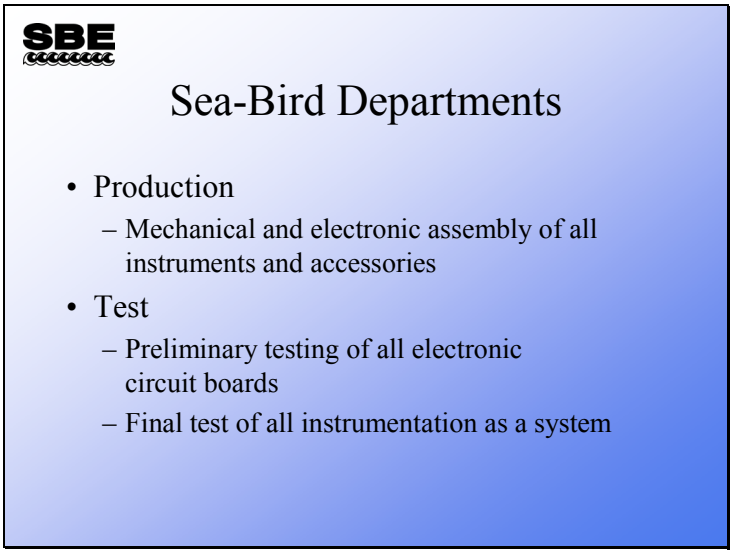


- SBE 9*plus* CTD/ 11*plus* Deck Unit:
  - Water sampler control
  - More power for auxiliary sensors
  - Any 9*plus* will work with any 11*plus*
  - Improved telemetry
- SBE 32 Carousel:
  - Improved reliability
  - Bottle closure in any order
  - Easier preparation for deployment
  - Mechanical compatibility with existing equipment
- Seacat *plus* enhancements:
  - Simultaneous P, T, and C sampling
  - Higher resolution for auxiliary sensors
  - More power available for auxiliary sensors
  - Ducted T and C

Sea-Bird Electronics Company History (*continued*)

- SBE 43 DO sensor:
  - Calibration stability, improved temperature response, continuous polarization, reduced hysteresis
- SBE 49 FastCAT CTD:
  - Fast sampling, low cost CTD with no internal power or memory, no auxiliary sensors – ideal for use with ROVs, AUVs, etc.
- Pumped MicroCATs:
  - Improved anti-foul protection and conductivity response
- SBE 26*plus*:
  - Real-time tide data, wave data, and wave statistics, and internal recording
  - Sampling flexibility, large memory, low power consumption
- SBE 39-IM Temperature Recorder:
  - Inductive modem version of high accuracy SBE 39
- SBE 53 BPR Bottom Pressure Recorder:
  - Full ocean depth water level with extremely high resolution, accuracy, and stability

Sea-Bird Electronics Organization



Sea-Bird's departments are:

- Production
- Test
- Customer Service
- Calibration
- Sales

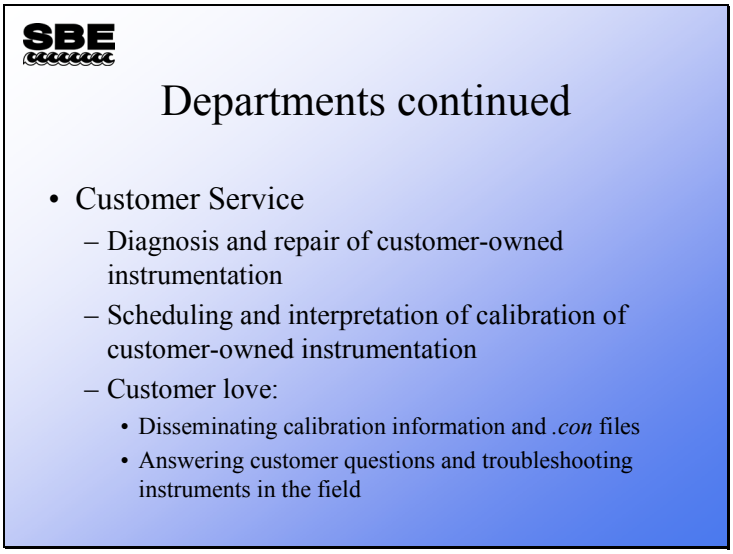
Production

The production department does all product assembly, from Carousels to conductivity cells. To support product assembly, printed circuit boards are populated with electronic components either at Sea-Bird or off site. Mechanical components are machined, coated, and labeled as appropriate. Sea-Bird performs all bonding of plastic to glass or metal.

Test

The test department performs preliminary acceptance testing on all printed circuit boards and final testing on each instrument system. Sea-Bird tests products by collecting data from each instrument while immersing it in one of the cold salt-water baths maintained for this purpose. The bath testing serves two purposes: to provide an operation check for the entire system and to ensure the instrument's ruggedness by exposing it to the shock of being plunged into a bath at approximately 2 – 3 ºC.

Sea-Bird Electronics Organization (*continued*)

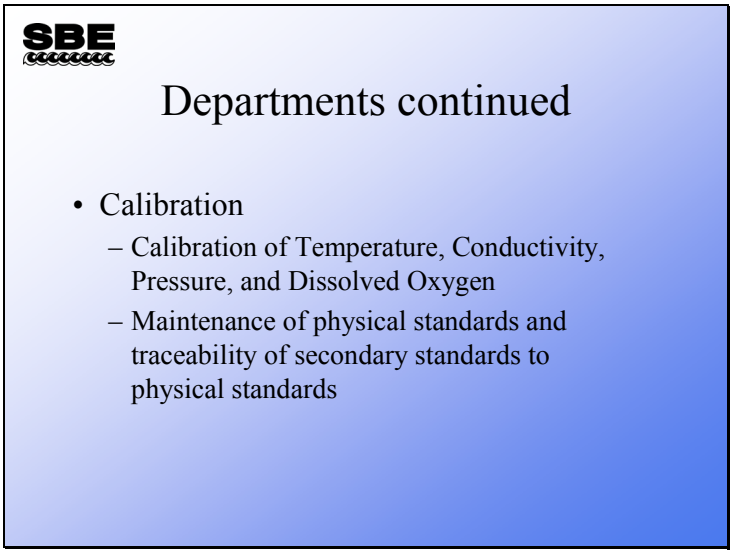


Customer Service

Customer service has the broadest set of responsibilities at Sea-Bird. Their activities include:

- Receiving equipment for maintenance and repair.
- Scheduling maintenance and repair activities with customers.
- Responding to customer requests for help with instrument operation.
- Interpreting and disseminating calibration information.
- Performing final checkout of all instruments that have been repaired or recalibrated.

Sea-Bird Electronics Organization (*continued*)

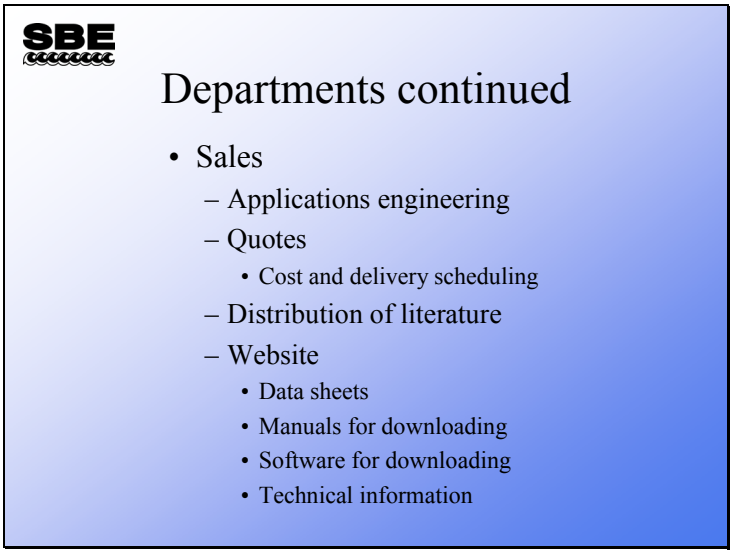


Calibration

The calibration department:

- Calibrates new sensors and re-calibrates sensors returned from the field.
- Maintains calibration histories for all sensors.
- Monitors new sensors being held at Sea-Bird until a sensor history, adequate for the precision specified for the sensor, exists.
- Maintains physical standards that allow temperature calibrations to be traced to the triple point of water and the melting point of gallium.
- Operates the Guildline Autosal laboratory salinometer as a conductivity standard.

Sea-Bird Electronics Organization (*continued*)



Sales

Sea-Bird's sales department acts as our ambassador to the oceanographic community in addition to:

- Providing application engineering

  Applications engineering means the customer describes their project and Sea-Bird makes recommendations for the equipment package to best suit their needs.

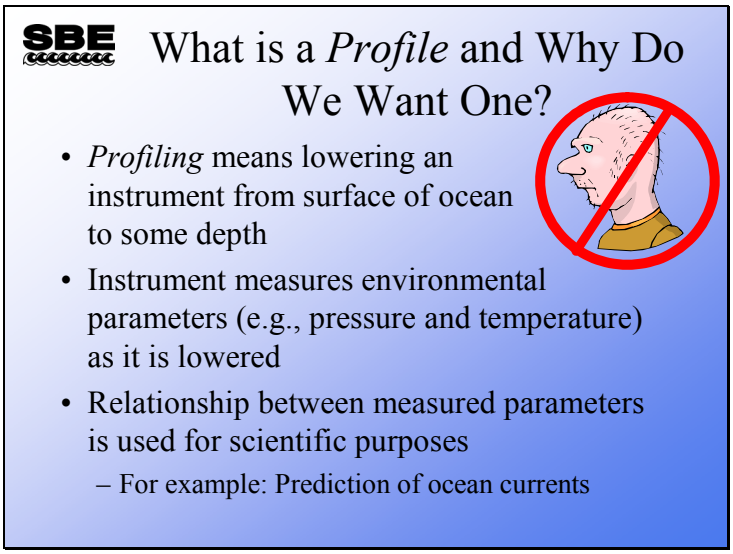
- Disseminating catalogs, manuals, and application notes.

- Maintaining the Sea-Bird web site.

  All information available as paper copy is also available electronically on www.seabird.com.

TIP: Sea-Bird's web site is the best source of up-to-date software and documentation.

Introduction: Ocean Profiling



A profile is a set of data for one or more environmental measurements, such as temperature and salinity, taken at a regular interval over the ocean depth. In the beginning, there were few options for obtaining ocean data. The most common means were:

- Hydrocasts

  Oceanographers hung water samplers on a cable lowered into the ocean, then dropped a weight down the cable to close the sample bottle and capture a water sample, released another weight to trigger the next sample bottle, and so on. Once the samples were retrieved, discrete samples could be analyzed for temperature and salinity. Accuracy was poor by modern standards, and only 12 – 24 data points were obtained for the whole water column. They yearned for more data points.

- Bathythermograph

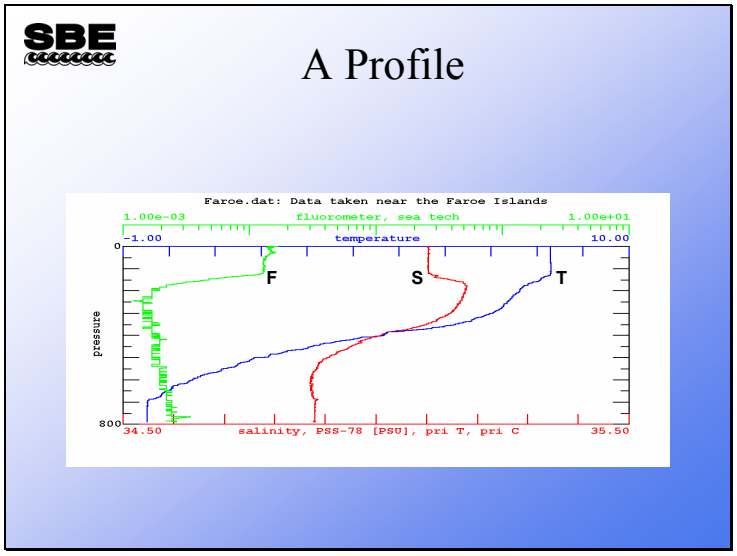
  The bathythermograph was towed from a ship as it was lowered on a cable. It scratched a trace of the temperature versus depth on a coated glass slide. This provided more points, but only for temperature and only for relatively shallow depths. People still yearned for more data.

- Modern sensors and profiling equipment

  Equipment that could make measurements and telemeter these measurements from the end of a conducting cable back to the ship was invented; now there were more points, and life was good. However, there was room for improvement. There has been steady refinement in profiling equipment, data is telemetered digitally, sensors are improved, water sampling equipment is attached to the measurement package, and samplers capture their water on command from the computer on the ship. There are sensors available to measure a wider variety of parameters.

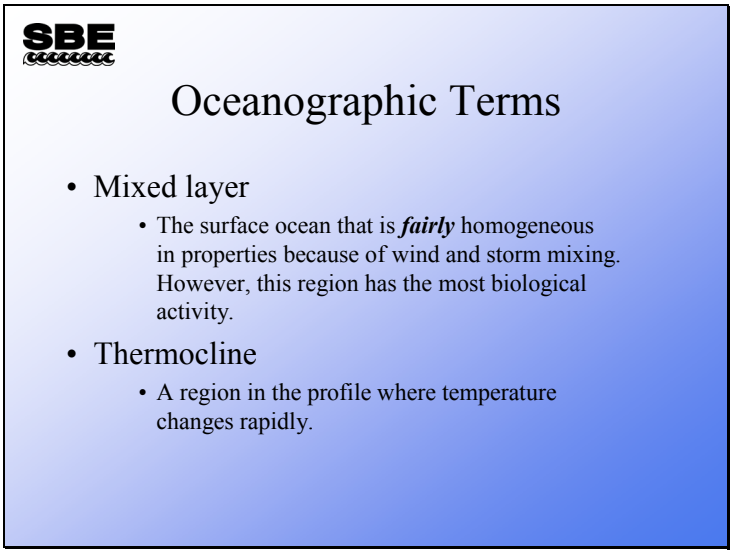
What do we do with our profile? We estimate deep ocean currents based on density profiles. We look for sharp density changes to investigate the interesting chemical and biological processes that go on there. We look for the boundaries of surface ocean currents. We look for the movements of different water masses near shore that indicate upwelling or currents that move sediment along the shore. We measure a sound velocity profile so we can refine our acoustic investigation of the ocean bottom. We discover the depth at which a basin becomes anoxic. We are only limited by our imagination.

Introduction: Ocean Profiling



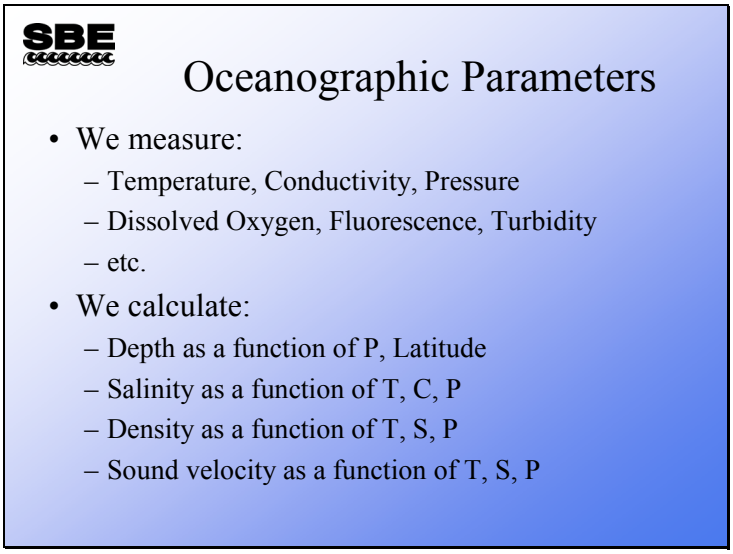
This profile was collected with an SBE 911*plus* system near the Faroe Islands.

Introduction: Oceanographic Terms



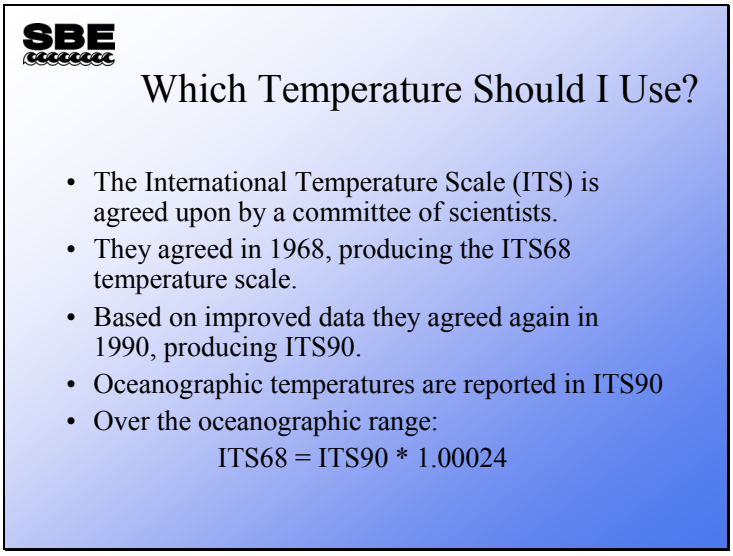
The ocean is often spoken of as a two-layer system: a mixed or surface layer and a deep layer. The mixed layer or surface layer is as it sounds, at the surface of the ocean and well mixed by wind and waves. The deep layer is separated from the surface by a region of rapidly changing temperature referred to as the thermocline. Because density is a strong function of temperature, the water in this area also changes sharply in density. The change in density makes it difficult for water in the deep ocean to mix with water in the surface ocean, effectively separating the deep layer from the mixed layer.

Introduction: Oceanographic Parameters



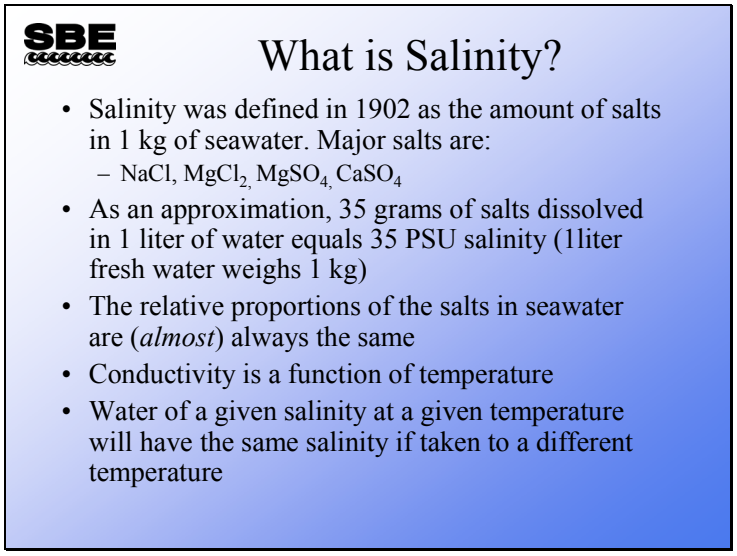
We measure physical quantities with Sea-Bird instruments. These quantities are then used to calculate the many parameters that are found in the analysis of oceanographic data. Because the calculated parameters rely on accurate measurement of the physical quantities, a small error in the original measurement can result in a large error in data analysis.

Introduction: Oceanographic Parameters (*continued*)



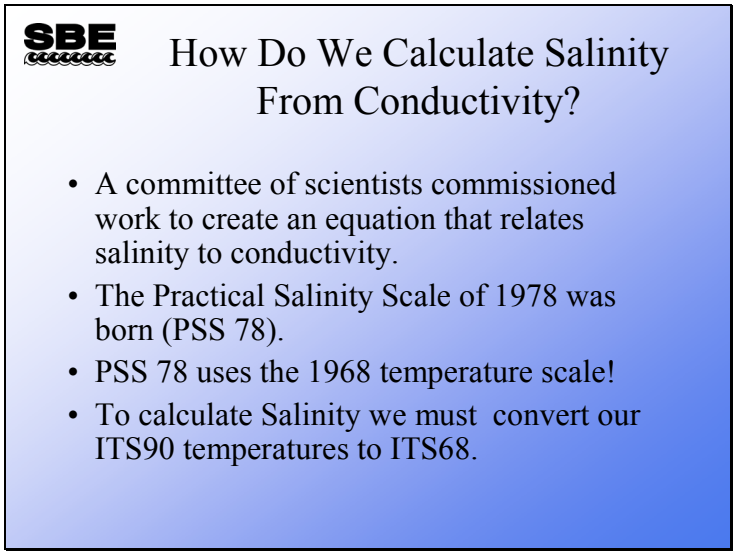
The calculation of the parameters mentioned on the previous slide is made with equations of the physical parameters. These equations were derived by gathering data in a laboratory relating T, P, and C to the parameter of interest, and statistically fitting the data to high order polynomials. The coefficients of the polynomials were determined using the 1968 temperature scale. So, to use these high-order polynomials, we must convert to the 1968 temperature scale for these calculations.

Introduction: Oceanographic Parameters (*continued*)



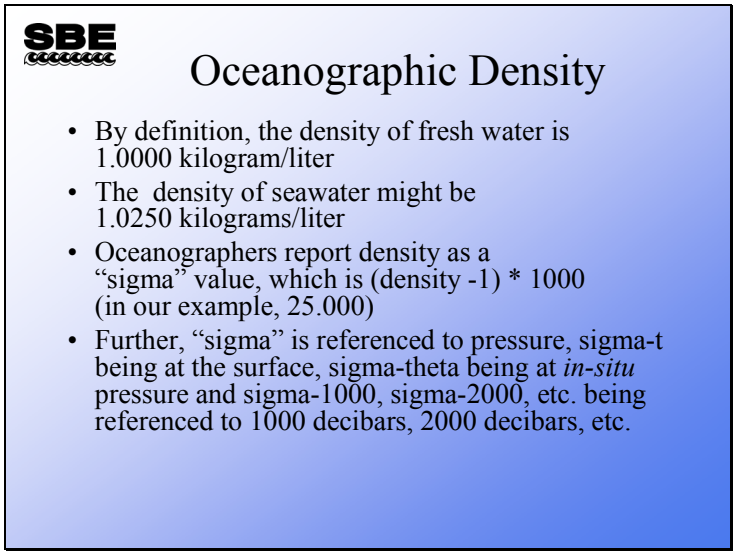
The relative proportion of each salt in seawater remains constant all over the ocean. This means that if we compare a kg of seawater at 35.000 PSU with a kg of seawater at 20.000 PSU, only the proportion of water in each is different. This does not hold true in areas of freshwater influence, such as river estuaries, or at high Latitudes when the ice is melting. Similarly it does not hold true in brines, either those formed by evaporation of seawater or from dissolution of salt domes or formed via volcanic influence.

Introduction: Oceanographic Parameters (*continued*)

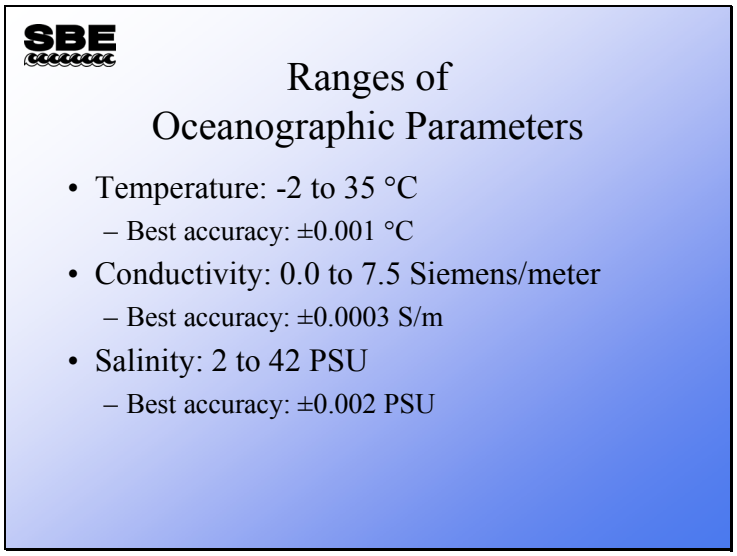


Salinity is calculated from several polynomials that characterize seawater's thermodynamic behavior in terms of conductivity, temperature, and pressure. The calculation is based on the ratio of the seawater sample conductivity to the conductivity of standard seawater. The polynomials were determined by statistically fitting the coefficients of these equations to laboratory results. The Practical Salinity Scale of 1978 is only valid when used with the temperature scale of 1968 over a temperature range of -2 °C to 35 °C, and it is only valid for seawater that has salinity between 2 and 42 practical salinity units (PSU).

Introduction: Oceanographic Parameters (*continued*)



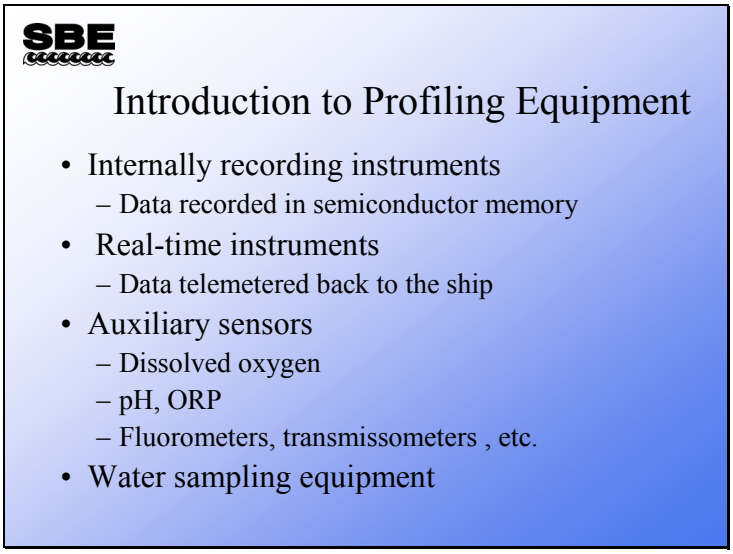
Introduction: Oceanographic Parameters (*continued*)



Module 1

Introduction to Profiling Equipment

Overview

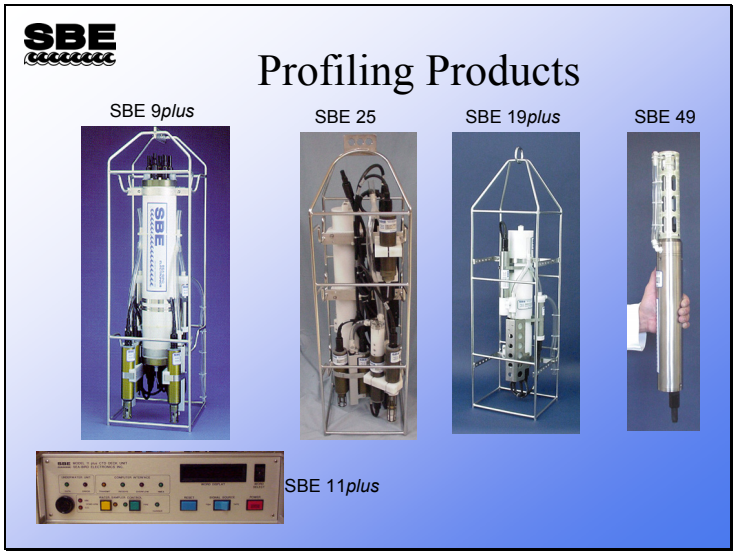


In this module we are going to present Sea-Bird's equipment offerings for profiling. We will present internally recording instruments first, followed by real-time instruments and then water sampling equipment.

At the end of this module you should be:

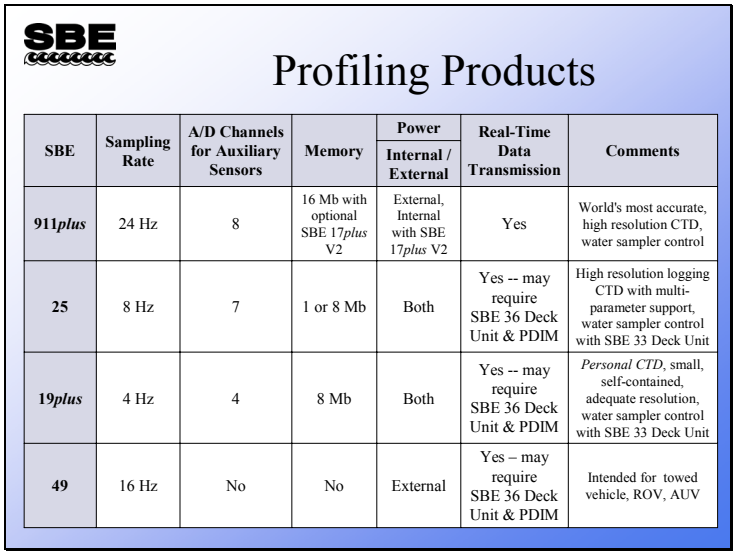
- Familiar with Sea-Bird's profiling product line.
- Aware of the difference between real-time and internally recording instruments.
- Familiar with the water sampling options available.
- Able to install Seasoft.

Profiling Products



Sea-Bird offers 4 profiling instruments: the real-time SBE 9*plus*/11*plus* system, the internally recording SBE 25 and SBE 19*plus*, and the real-time SBE 49. The capabilities of these instruments are contrasted in the following pages.

Profiling Products (*continued*)



SBE	Sampling Rate	A/D Channels for Auxiliary Sensors	Memory	Power	Real-Time Data Transmission	Comments
				Internal / External		
911*plus*	24 Hz	8	16 Mb with optional SBE 17*plus* V2	External, Internal with SBE 17*plus* V2	Yes	World's most accurate, high resolution CTD, water sampler control
25	8 Hz	7	1 or 8 Mb	Both	Yes -- may require SBE 36 Deck Unit & PDIM	High resolution logging CTD with multi-parameter support, water sampler control with SBE 33 Deck Unit
19*plus*	4 Hz	4	8 Mb	Both	Yes -- may require SBE 36 Deck Unit & PDIM	*Personal CTD*, small, self-contained, adequate resolution, water sampler control with SBE 33 Deck Unit
49	16 Hz	No	No	External	Yes – may require SBE 36 Deck Unit & PDIM	Intended for towed vehicle, ROV, AUV

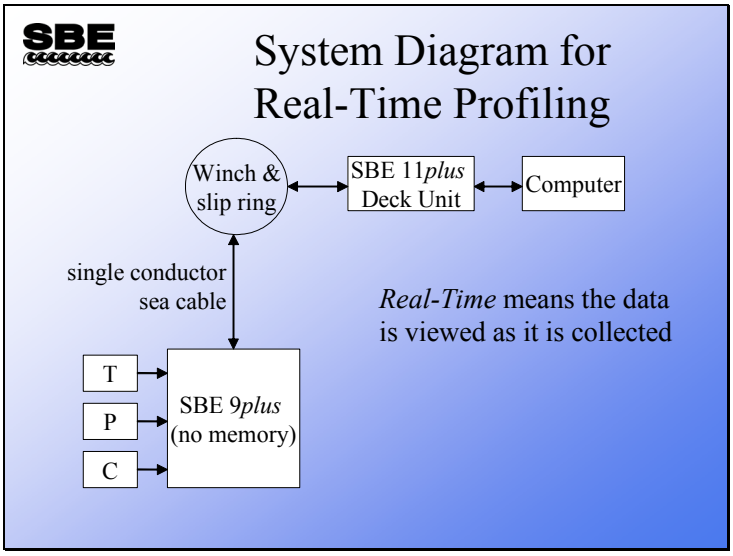
Sea-Bird's flagship CTD is the SBE 9*plus* and SBE 11*plus*. The 9*plus* is the underwater part of the system; it houses acquisition, telemetry, and power supply circuitry. The 9*plus* receives power from the 11*plus* deck unit and operates over more than 10 kilometers of sea cable. It can operate several types of water samplers and may be configured with a serial port multiplexed into the data stream, to accommodate instruments with serial output rather than the traditional voltage or frequency. It comes standard with pressure, 2 temperature and 2 conductivity channels, and 8 voltage channels.

The SBE 25 features internal recording at up to an 8 Hz sample rate. It supports temperature, conductivity, and pressure, plus 7 voltage channels. The 25 makes a smaller instrument package and is battery powered with semiconductor memory.

The SBE 19 has been in the field since 1987, and there are over 2500 instruments in use at present. The SBE 19*plus* is an enhancement of the venerable SBE 19. It is also battery powered with internal memory. It features independent temperature and conductivity channels, an integral T-C duct (hardware to improve the flow of water past the sensors), and an improved sampling protocol. The 19*plus* samples up to a rate of 4 Hz and averages 1 to 32767 scans (decreases the sample rate).

The SBE 49 is an integrated CTD sensor intended for use as a modular component in towed vehicles, ROVs, AUVs, or other platforms that can supply DC power and acquire serial data. The 49's pump-controlled, TC-ducted flow minimizes salinity spiking. The SBE 49 samples at 16 Hz.

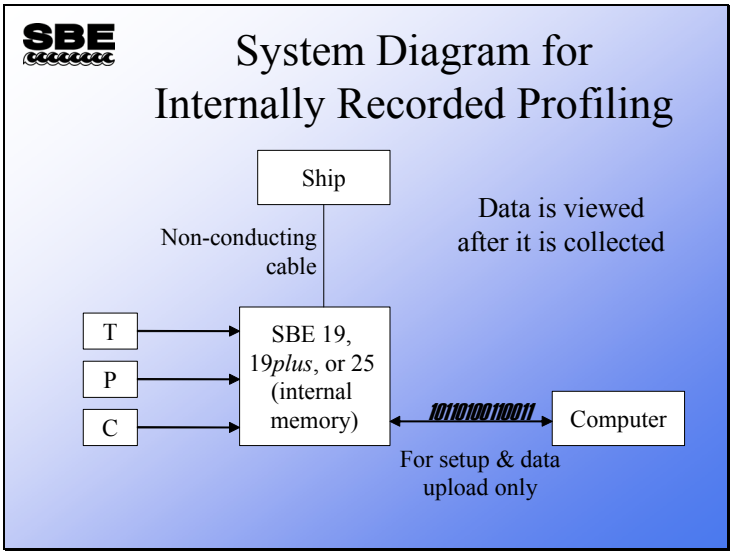
Real-Time Profiling



Real-time profiling means that you are viewing and storing data on your computer at almost the same time that the measurement is being made at the end of the winch cable. The *almost* part is because there is some time involved in packaging the bits up and sending them up the wire to the deck unit and then onto your computer.

The system consists of sensors that convert environmental parameters to electrically measurable quantities like voltage or frequency. The data acquisition component measures the sensors' outputs and telemeters them up the sea cable. The deck unit receives the telemetered data, does some minor manipulation, and transmits the data to your computer for display and storage. In the middle of all this is the winch and slip ring, which provide the mechanical means of getting the instrument package down into the ocean and the electrical data stream up to the deck unit.

Cabling for Internally Recorded Profiling



Internally recorded profiling means that the measurements are stored in semiconductor memory inside the instrument and are downloaded to your computer and viewed *after* the equipment is on deck. The ship is not required to have a sea cable with an internal conductor.

The measurement system consists of sensors that convert environmental parameters to electrically measurable quantities. The data acquisition portion of the system converts the sensor output to digital data and stores it internally.

Conductivity, Temperature, and Pressure Sensors

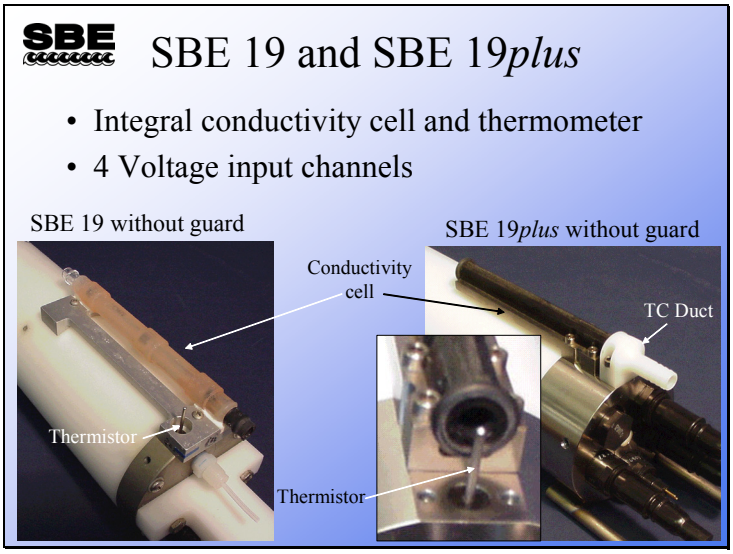
Conductivity, Temperature, and Depth (CTD)

- Depth is derived from a pressure sensor
  - Pressure sensor is typically internal to the main pressure housing of the CTD
- Conductivity and temperature sensors may be mounted internally or externally

SBE 4 Conductivity Sensor

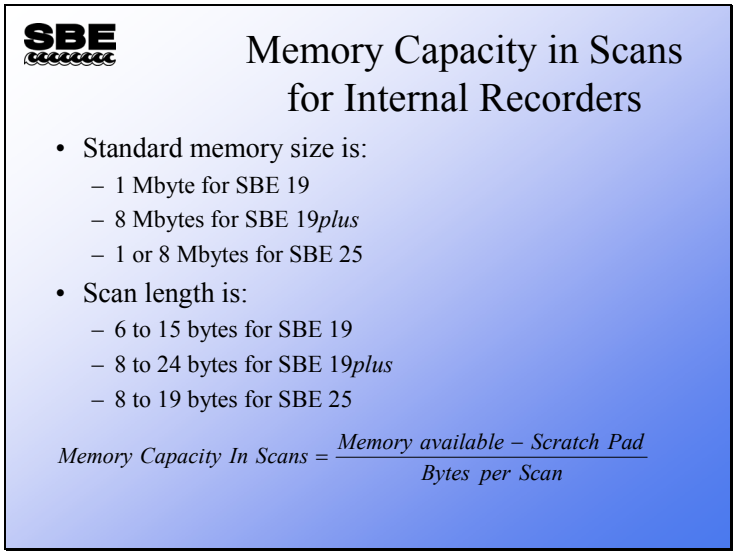
SBE 3
Temperature Sensor

SBE 19 Versus SBE 19*plus*, Sensor Placement



The SBE 19 has side-by-side temperature and conductivity sensors. The SBE 19*plus* features inline sensors and an integral ducting system, which ensures that water that passes the thermometer goes into the conductivity cell.

Calculating Memory Capacity in Scans



SBE 19:

Pressure Sensor	No External Voltages Sampled	4 External Voltages Sampled
Paine	ttttccccpppp	ttttccccuuuvvvxxxyyypppp
Digiquartz	ttttccccpppppppdddd	ttttccccpppppppuuuvvvxxxyyydddd

where:
tttt = 2 bytes of temperature frequency cccc = 2 bytes of conductivity frequency
pppp = 2 bytes of pressure (Paine strain gauge)
pppppp = 3 bytes of pressure (Digiquartz)
dddd = 2 bytes of pressure sensor temperature compensation
uuu through yyy = 12 bits representing stored voltages

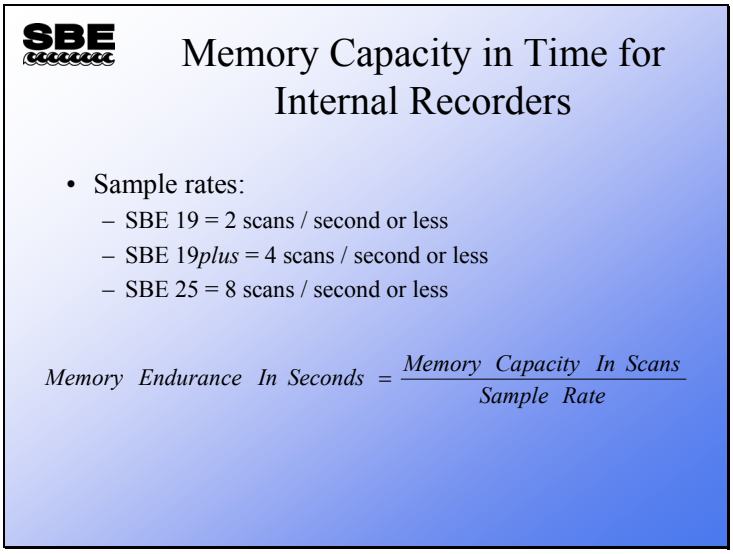
SBE 19*plus* in Profiling mode:

No external voltages sampled: ttttttccccccpppppppdddd
Four external voltages sampled: ttttttccccccpppppppddddvvvvvvvvvvvvvvvv
where:
ttttt = 3 bytes of temperature frequency cccccc = 3 bytes of conductivity frequency
pppppp = 3 bytes of pressure data
dddd = 2 bytes of pressure sensor temperature compensation voltage
vvvv = 2 bytes representing each stored voltage

SBE 25:

No external voltages sampled: ttttttccccccsppp
Seven external voltages sampled: ttttttccccccsppppuuuvvvwwwxxxyyyzzz0aaa
where:
ttttt = 3 bytes of temperature frequency cccccc = 3 bytes of conductivity frequency
s = sign character for pressure ppp = 12 bits representing pressure
uuu through zzz and aaa = 12 bits representing stored voltages
0 = 4 bits all zero (used to make an even number of characters)

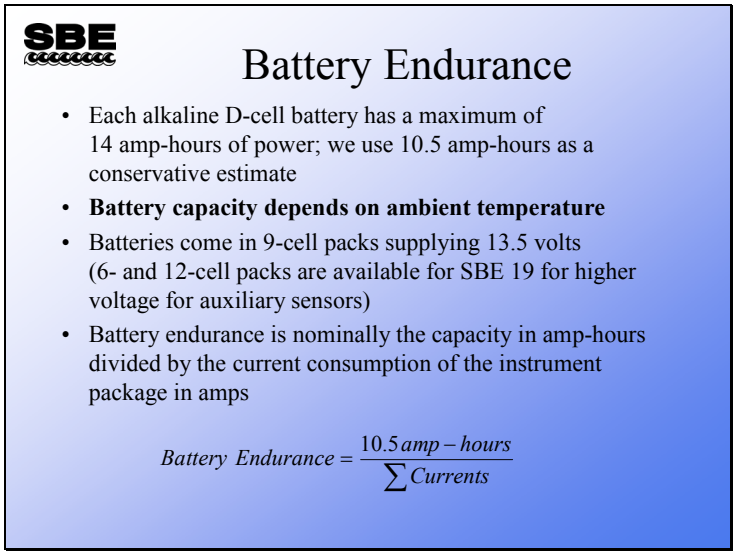
Calculating Memory Capacity in Time



Memory endurance in time is the ratio of memory capacity in scans divided by the instrument sample rate.

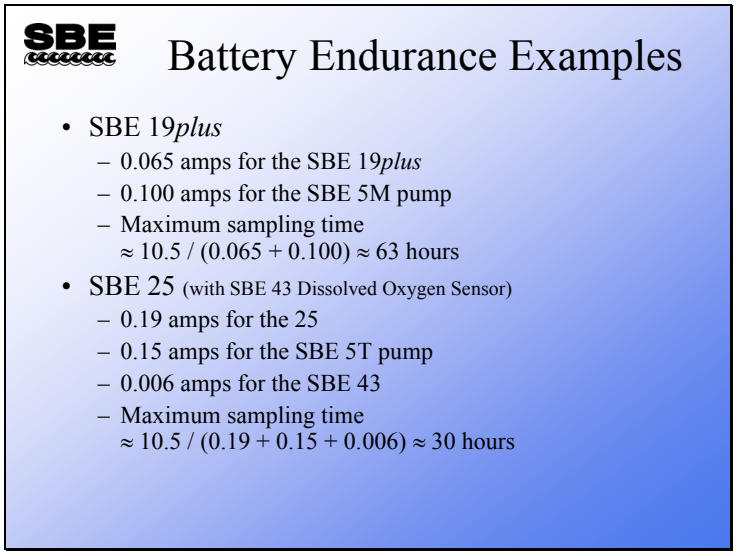
- The SBE 19 sample rate can vary from 2 samples per second to 4 minutes between samples.
- The SBE 19*plus* sample rate is 4 Hz (4 samples per second); however, you can average between 1 and 32767 samples, for a range of 0.25 seconds to 2.3 hours between samples stored in memory.
- The SBE 25 samples at 8 Hz and can average between 1 and 8 scans, for a range of 0.125 seconds to 1 second between samples stored in memory.

Calculating Battery Endurance in Time

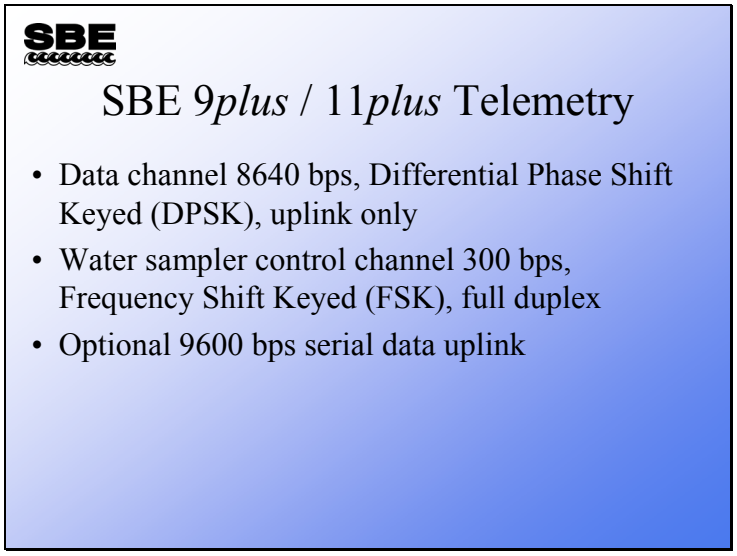


Battery endurance is difficult to estimate, because a battery's life depends on the ambient temperature. Moreover, batteries tend to lose their capacity as they age. The information on this slide is a good rule of thumb for alkaline batteries. However, for critical work, consider that batteries are cheap, so you might as well start with a new set.

Battery Endurance Examples



SBE 9*plus*/11*plus* Telemetry Channels

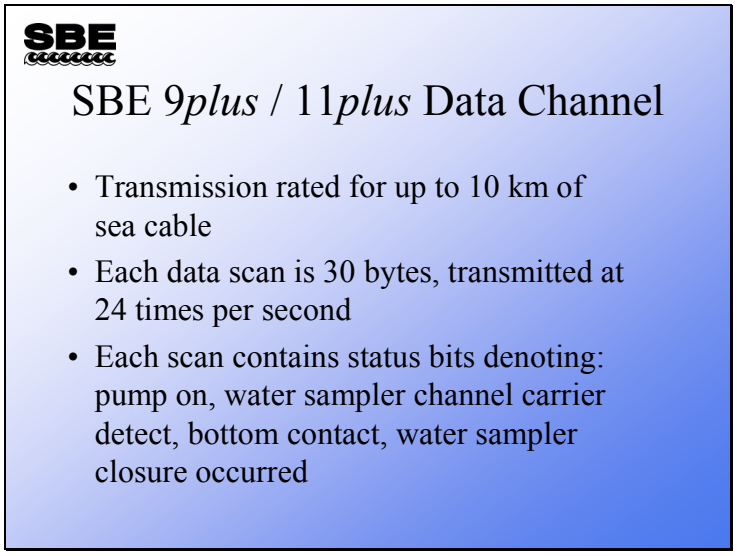


The 9*plus* / 11*plus* CTD has two standard telemetry channels, the data channel and the water sampler control channel (often referred to as the modem channel). The data channel is for uplink only; the data flows from the 9*plus* to the 11*plus*. The water sampler control channel is duplex; data flows both ways, from the 9*plus* to the 11*plus* and from the 11*plus* to the 9*plus*.

The data channel operates at 8640 bits per second (8640 baud) and transmits from the 9*plus* as a Differential Phase Shift Keyed (DPSK) signal. Binary data is packaged into standard 10-bit serial frames (8 data bits, 1 start bit, 1 stop bit, and no parity); it is modulated to 34.5 kHz and a 0 bit is represented as 0 degree phase, a 1 bit as 180 degree phase. The 11*plus* demodulates the telemetry and standard serial receivers (UART) accept the serial frame.

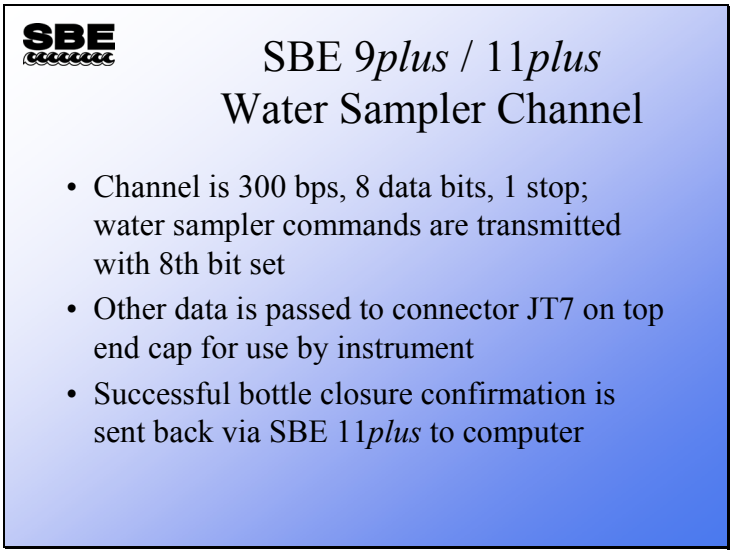
The water sampler channel is a 300 bit per second (300 baud) Frequency Shift Keyed (FSK) duplex channel, modulated to 1 kHz for the downlink and 2 kHz for the uplink. This channel is meant for water sampler control and for communications with user instrumentation. Water sampler control information has the 8th bit in a 7 bit ASCII character set. Any data without the 8th bit set is assumed to be meant for a remote instrument and is passed to the center bulkhead connector of the top end cap.

SBE 9*plus*/11*plus* Data Telemetry



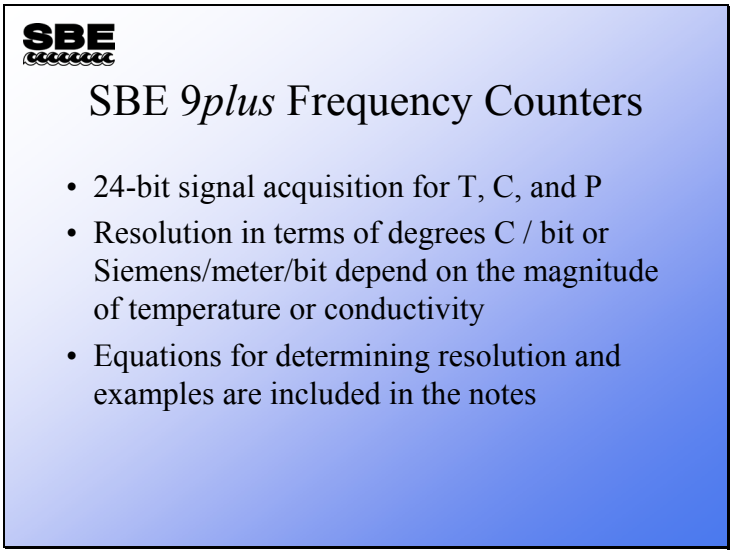
The data transmission rate of the 9*plus* is constrained by the 24 Hz scan rate. Of the 30 bytes that make up a scan, 29 of them are transmitted in standard asynchronous format, 1 start bit, 8 data bits, and 1 stop bit. The 30th byte is all zeros; it is not transmitted. This lack of a data byte is used by the 11*plus* and the 17*plus* to synchronize the data acquisition. Synchronization occurs with each data scan. As an option, the data transmission speed can be doubled and serial data at 9600 baud from a remote instrument can be time dimension multiplexed into the telemetry stream. This option requires a hardware change; it finds use with some optical instrumentation that transmits data at 9600 baud. The disadvantage to deploying this option is the data transmission is not as robust, and some lower quality sea cables will not allow transmission to occur over the whole 10 km.

SBE 9*plus*/11*plus* Water Sampler Telemetry



All water sampler communications are carried out over the 300-baud FSK modem channel. This is a separate, full-duplex communication channel that is frequency domain multiplexed onto the single conductor sea cable. You have the option of commanding water sampler closures with the buttons on the deck unit or via the computer keyboard. If you want to use the computer, you must have two serial ports installed on your computer.

SBE 9*plus* Frequency Acquisition



Frequency counters require a reference frequency to count the sample frequency against. Consider that if you want to measure frequency in Hertz (cycles/second), you need to know how long a second is. The resolution of the type of counters employed in the 9*plus* depends on the frequency of the sample, the scan rate, and the frequency of the reference.

$$Resolution\,(Hz/Bit) = Scan\,Rate \times \left(\frac{F_s}{F_r}\right)$$

Where:
F_s is the sensor frequency
F_r is the CTD reference frequency (6,912,000Hz for C & T; 27,648,000 for P)

To find resolution in scientific units, we need to divide resolution by sensitivity (Hz/scientific unit). Approximate values can be obtained from the sensor calibration sheet. Some examples follow. These are for illustration only; your computer will use higher precision math and the appropriate calibration equations for your sensors.

Temperature:

At -1°C, Fs = 2100 Hz, Sensitivity = 48 Hz/°C
Resolution = 0.00015°C per bit

At 31°C, Fs = 4000 Hz, Sensitivity = 76 Hz/°C
Resolution = 0.00018°C per bit

Conductivity:

At 1.4 Seimens/meter (S/m), Fs = 5000 Hz, Sensitivity = 1900 Hz/(S/m)
Resolution = 0.0000091 S/m per bit

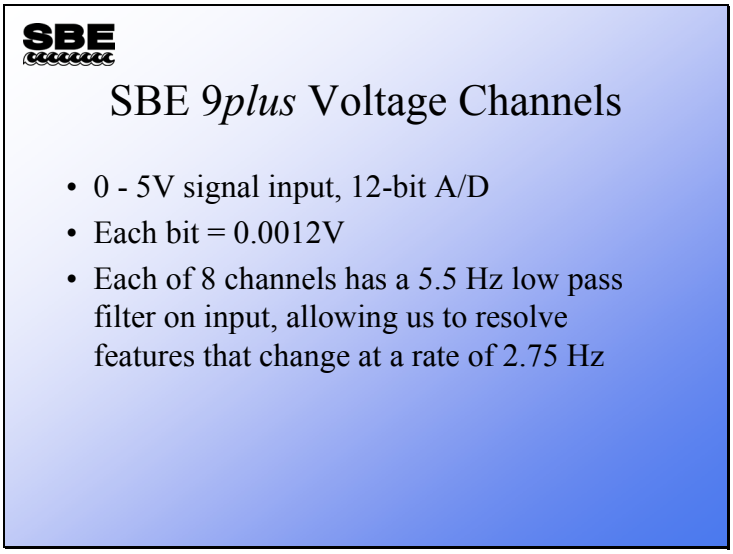
At 5.8 S/m, Fs = 11000 Hz, Sensitivity = 960 Hz/(S/m)
Resolution = 0.0000398 S/m per bit

Pressure (10,000 psi range Digiquartz sensor, with a conversion factor of 1.46 psi/dbar):

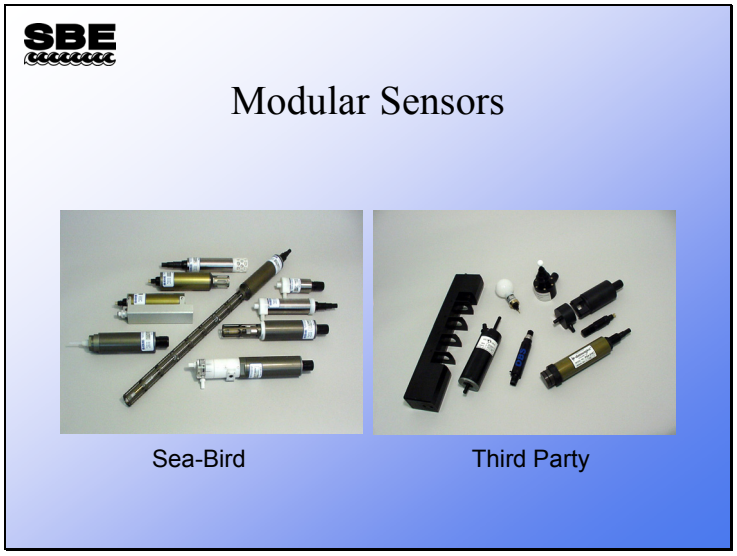
At 0 dbar, Fs = 33994 Hz, Sensitivity = 0.614 Hz/dbar
Resolution = 0.041 dbar per bit

At 6800 dbar, Fs = 38,480 Hz, Sensitivity = 0.614 Hz/dbar
Resolution = 0.054 dbar per bit

SBE 9*plus* Voltage Acquisition

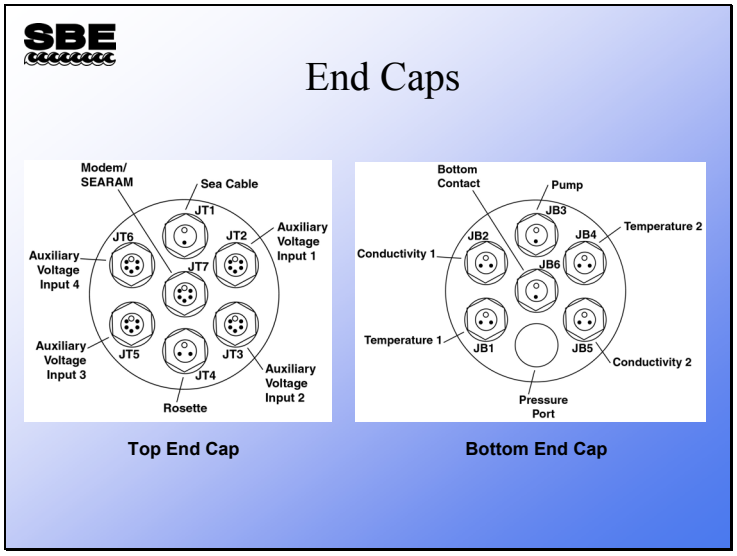


Modular Sensors, SBE and Others



Sea-Bird offers a variety of modular sensors of our own manufacture and also many from other manufacturers. These sensors have various outputs: voltage, frequency, or serial ASCII data. In addition to temperature and conductivity, dissolved oxygen and pH are offered, as are oxidation potential, light, transmittance, fluorescence, and turbidity.

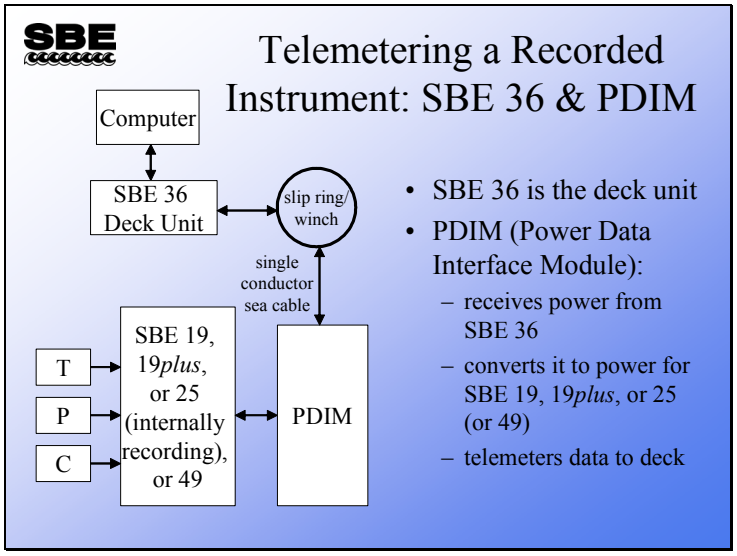
SBE 9*plus* End Cap Connections



The top end cap of the 9*plus* has bulkhead connectors for all auxiliary sensors. Auxiliary sensors are those that are not temperature, conductivity, or pressure. Each auxiliary bulkhead has inputs for two 0 – 5V differential input channels. In addition, there is a 2-pin connector for the sea cable and a 3-pin connector for a GO 1015 rosette sampler. The center connector connects to the SBE 17*plus* (a memory module), a remote instrument, or an SBE 32 Carousel Water Sampler.

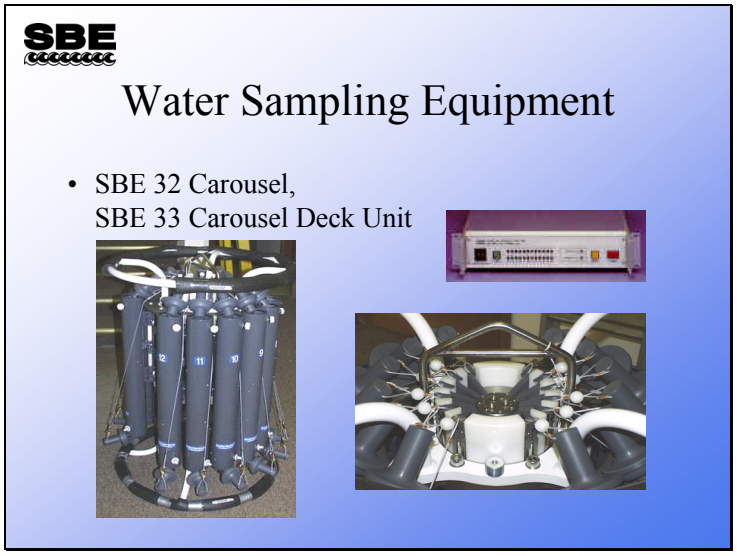
The bottom end cap has connectors for pairs of temperature and conductivity sensors, pump power, and a bottom contact switch. The bottom contact switch is mechanical, with a weight that hangs below the instrument package. When the weight contacts the ocean bottom, a bit is set in the data stream and an alarm in the SBE 11*plus* deck unit sounds.

Real-Time Options for Internally Recording Instruments



The SBE 36 and PDIM provide power and telemetry, but no water sampling capability.

Water Sampling Equipment



As a companion to CTD profilers, Sea-Bird supplies water sampling equipment. Sea-Bird manufactures the framework, mechanism for closing bottles, and deck power supply and sampler control. The water sample bottles themselves are not manufactured by Sea-Bird. The SBE 32 is the portion of the equipment that triggers the bottle closure.

The Carousel trigger mechanism is an electro-mechanical device. It operates by energizing a solenoid magnet that pulls a mechanical trigger, releasing the nylon lanyards that hold the top and bottom caps of the water sampler open.

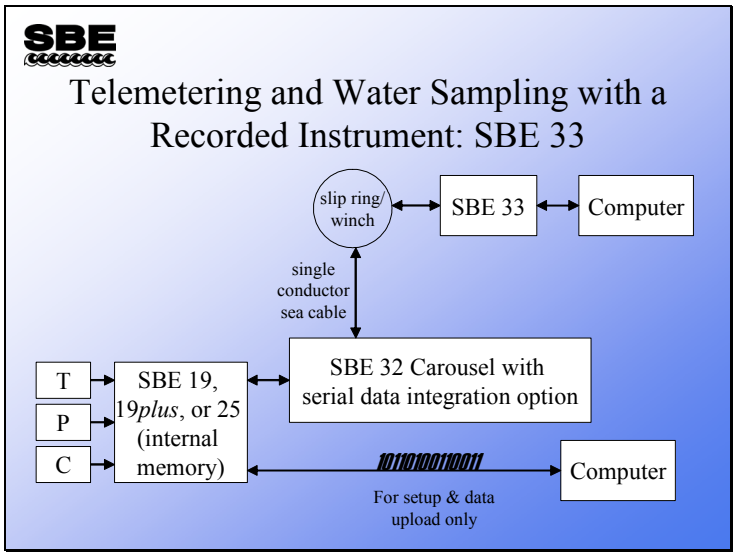
For the SBE 9*plus* CTD, the 11*plus* Deck Unit provides real-time water sampler control. The SBE 33 Deck Unit shown above provides real-time water sampler control for internally recording CTDs (SBE 19, 19*plus*, or 25).

Water Sampling Equipment (*continued*)

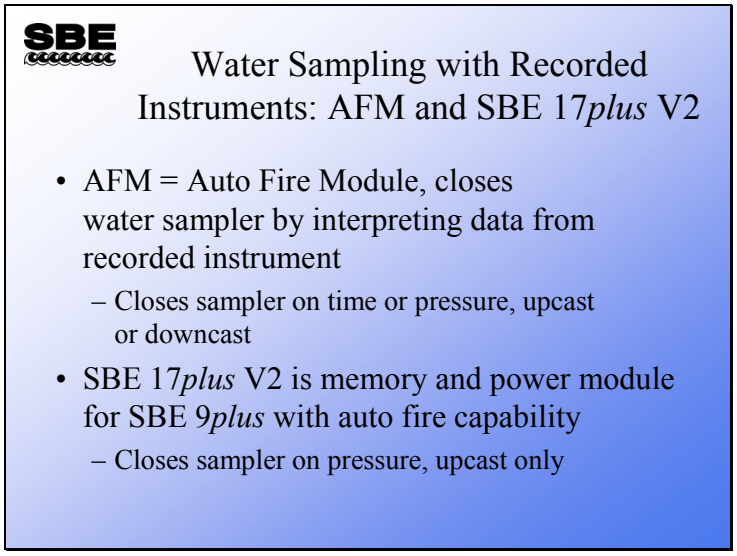
Water Sampling Products

Carousel	Number of Bottles	Bottle Size (liters)	CTD	Control	
				Real-Time	Self-Contained (auto bottle firing)
SBE 32 (standard)	12	1.7 - 30	SBE 9*plus*	SBE 11*plus* Deck Unit	SBE 17*plus* V2
	24	1.7 - 12			
	36	Consult factory			
	12	1.7 - 30	SBE 19, 19*plus*, or 25	SBE 33 Deck Unit	90208 Auto Fire Module
	24	1.7 - 12			
	36	Consult factory			
SBE 32C (compact)	12	1.7 - 8	SBE 9*plus*	SBE 11*plus* Deck Unit	SBE 17*plus* V2
			SBE 19, 19*plus*, 25 or 50	SBE 33 Deck Unit	Auto Fire Module
SBE 32SC (sub-compact)	12	1.7 or 2.5	SBE 19, 19*plus*, 25 or 50	SBE 33 Deck Unit	Auto Fire Module

Water Sampling in Real-Time for Internally Recording Instruments

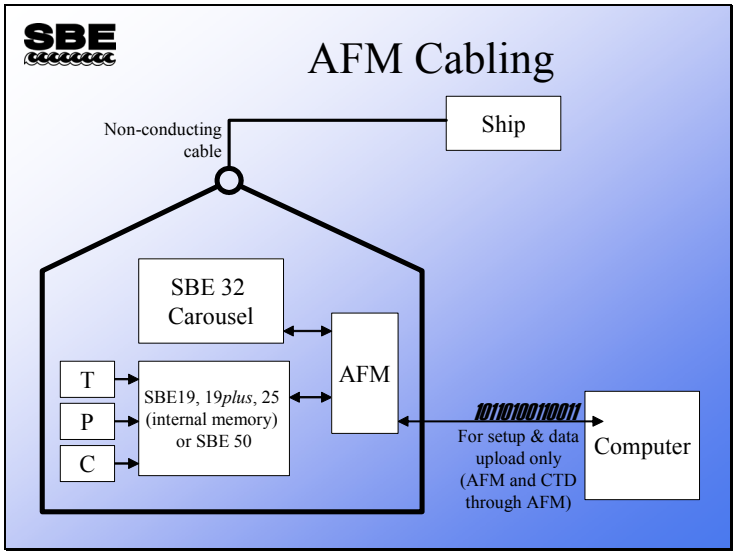


Water Sampling for Internally Recording Instruments



Internally recording instruments output a real-time, RS-232 serial data stream. This data stream is suitable for real-time telemetry over short cables only. The data stream is used by the AFM to monitor the depth of the sampling package for the purpose of closing water samplers.

Cabling for Water Sampling with the AFM



The AFM is programmed to close water samplers at the required depths, and then it is armed. It receives pressure data from the CTD; when the closure parameter for a water sample has been met, it actuates the Carousel and records a small amount of CTD data. When the CTD is retrieved, the data in the CTD and AFM are uploaded to the computer. The data in the AFM is used in post-processing to get a table of CTD parameters to go with whatever is gleaned from the water samples.

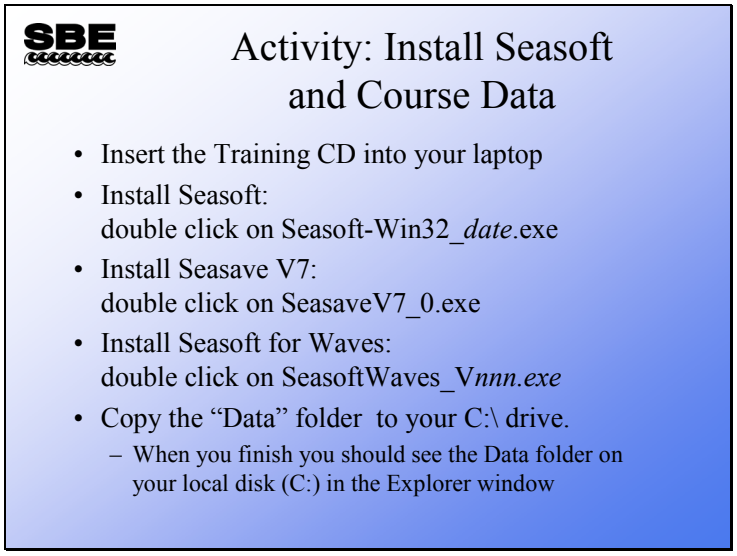
Battery Power and Internal Recording for the SBE 9*plus*

The SBE 17*plus* V2 acts as battery power and internally recording memory for the SBE 9*plus*. This device has the capability to close water samplers as well. It only closes bottles on the upcast.

Autonomous Profiling

The SBE 41 and 41cp are CTDs that are used with buoyancy engines. After deployment they become negatively buoyant, sinking to ~1000 meters, resting for 10 days, and then making themselves positively buoyant, collecting a profile as they rise through the ocean. Once on the surface, they transmit their data via a satellite back to the scientist who deployed them. Because they receive no handling after deployment and have minimal time on the surface, they provide an excellent example of conductivity sensor drift in an optimum environment.

Activity



- **Seasoft-Win32_*date*.exe** installs programs intended for use with CTDs: Seaterm and SeatermAF (terminal programs), Seasave (real-time data acquisition program), and SBE Data Processing (post-processing program).
- We are also installing another version of Seasave (real-time data acquisition program) separately – **SeasaveV7** is a Beta version of a major revision that has not yet been incorporated in the suite installation. We will be using the Beta version in the course instead of the version installed with Seasoft.
- **Seasoft for Waves** is intended for use with our wave and tide gauge products, which we will talk about on the last day of the class.

Additional setup notes:

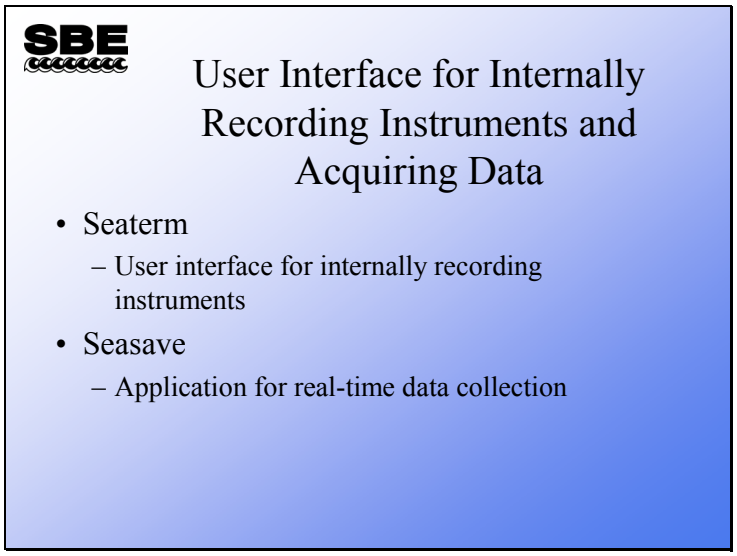
If the Explorer window does not show file extensions (.con, .dat, .hex, etc.) and/or if the Explorer window does not show the full path in the address bar, we suggest you change the settings to make your life easier for this course. Follow these directions (written for Windows XP Professional) to change settings:

1. Select Start / Control Panel.
2. Select Folder Options.
3. Click the View tab.
   A. **Unclick** *Hide extensions for known file types.*
   B. Click *Display the full path in the address bar.*
   C. Click Apply.
   D. Click OK.

Module 2

Setup and Acquiring Data

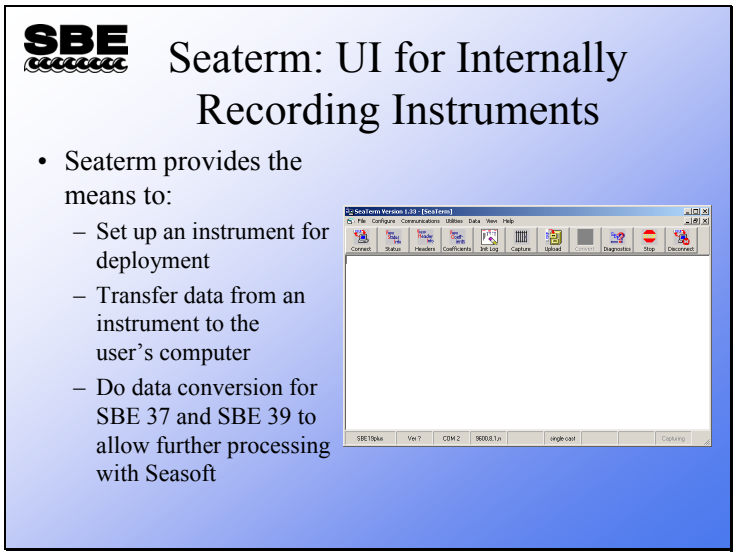
Overview



We are going to discuss Seaterm, the user interface or terminal program for internally recording instruments. We will also discuss Seasave, an application that collects real-time data and saves it to a file. By the end of this module you should be able to:

- Use Seaterm to prepare an internally recording instrument for deployment.
- Use Seaterm to transfer data stored in an internally recording instrument to your computer.
- Set up Seasave to collect data in the manner that best suits your application.
- Use Seasave to manipulate your .con file as appropriate for your instrument and auxiliary sensors.
- Use Seasave's capability for making file header annotations.
- Use Seasave's capability for marking points of interest in the real-time data and saving marked data into a file.

Seaterm: User Interface for Internally Recorded Instruments



Below is a summary of the function of each of the buttons:

Connect: To begin communicating with your instrument, you must first establish communication by clicking the Connect button. After Seaterm has received the *S*> prompt from the instrument, it will allow you to use the other buttons.

Status: Sends the command to cause the instrument to transmit its current status.

Headers: Sends the command to cause the instrument to list the headers for each of the recorded casts.

Coefficients: For instruments that are capable of transmitting data in scientific units (e.g., temperature in deg C), causes the instrument to list its calibration coefficients.

Init Log: Sets up the instrument for logging; memory is cleared and the instrument is put to sleep. Not applicable to all instruments.

Capture: Causes Seaterm to write everything received from the remote instrument to a file; useful for some real-time operations and for diagnostics.

Upload: Starts the protocol for transferring data between the instrument and your computer.

Convert: A conversion utility for the SBE 37 and 39; converted data can be processed with Seasoft.

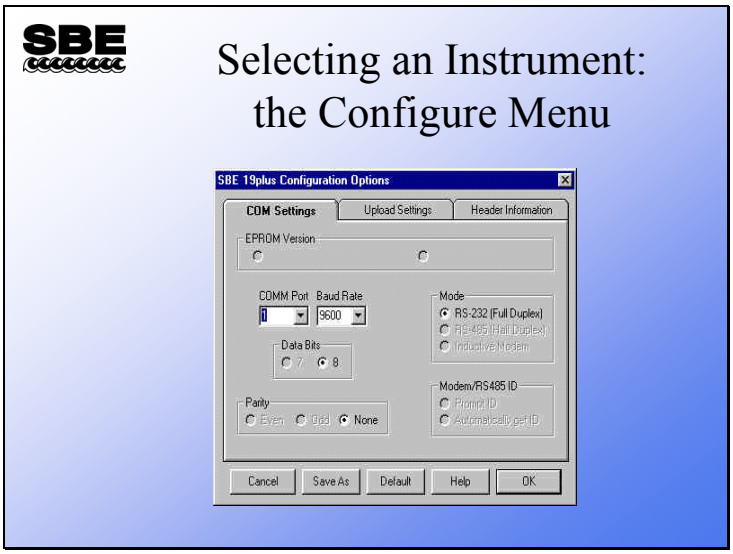
Diagnostics: Starts a protocol for saving diagnostic information to a file that you can e-mail to Sea-Bird.

Stop: Sends 10 escape characters, causing the instrument to halt data transfers or continuous measurements.

Disconnect: Causes Seaterm to release the serial port so you can run another program, such as Seasave, without exiting Seaterm.

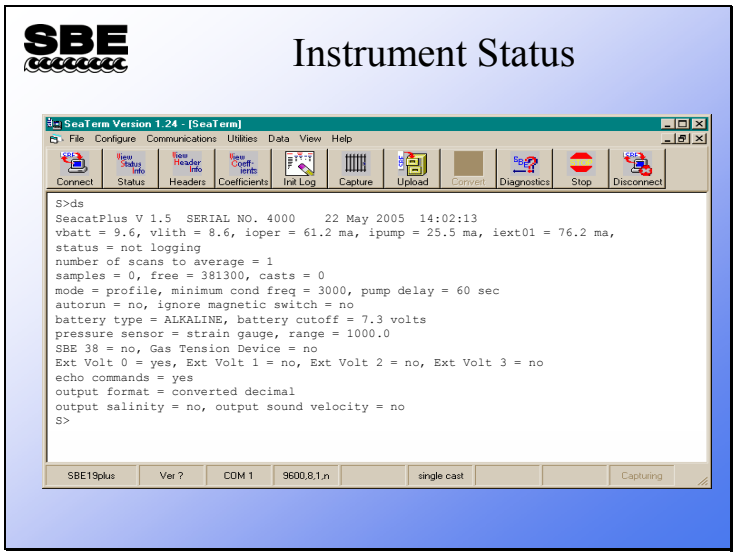
The status panel across the bottom shows which instrument Seaterm thinks it is connected to, the version of the firmware that the instrument is running, the Com port that Seaterm is using, and the communication parameters (baud, data bits, stop bits, parity). Also shown in the status panel are the data transfer protocol and if the program is capturing communications to a file.

Seaterm: Selecting an Instrument Configuration



Seaterm supports all of Sea-Bird's internally recording instruments. To select which instrument you will be communicating with, click the Configure menu and select the appropriate instrument. The Configuration dialog box for the instrument you have chosen will pop up. The first tab has choices for firmware revision; older firmware does not have the capabilities that newer ones do, so some of your choices are limited by the firmware revision of your instrument. Com port, baud rate, data bits, and parity are those appropriate to your instrument. Mode selects communication mode: RS-232, RS-485, or Inductive Modem. RS-232 is standard serial communications. RS-485 is 4-wire serial communications, which allows instruments to be placed in parallel on the communications cable and each instrument to be addressed uniquely. Inductive Modem is a proprietary protocol that Sea-Bird has developed for use in moorings; it also supports instruments deployed in parallel, with each instrument assigned a unique address.
If RS-485 or Inductive Modem is chosen, Seaterm will query the instrument for its address or you may input one.

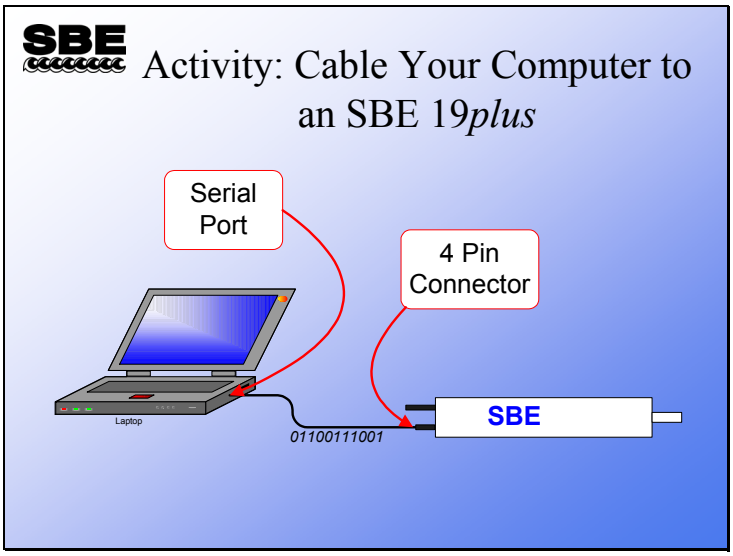
Seaterm: Instrument Status



The instrument status report contains much valuable information:

- The instrument type, firmware revision, serial number, and date and time.
- The main battery voltage and the back-up battery voltage. Operating current, pump current, and current to external voltage sensors provide an indication of the battery lifetime you can expect, as well as the health of the instrument in general.
- The status entry indicates whether the instrument is logging data or not.
- The number of scans to average sets the sample rate.
- Memory: scans collected, number of scans that can fit in the remaining memory, and the number of casts collected.
- The SBE 19*plus* can operate in profiling mode or moored mode. In profiling mode the instrument is powered continuously, while in moored mode the instrument powers down between samples. The 19*plus* waits until the conductivity sensor's frequency rises, indicating that there is water in the cell, to turn on the pump. The threshold for the pump turn-on is the minimum conductivity frequency. In addition, there is a time delay from when that frequency is reached to the pump turn-on to allow air to leave the plumbing.
- If the 19*plus* is set to autorun=yes, it starts logging automatically when external power is applied. If the 19*plus* is set to ignore its magnetic switch, it can only be made to collect data via commands sent by the terminal program.
- Battery type can be Alkaline, NiMH, or Ni-Cad. Battery type influences the cutoff voltage, which is the power level that causes the instrument to shut itself off because it does not have sufficient power to sample.
- Pressure sensor type and range are entered at the factory.
- Which auxiliary sensors are logged.
- Whether to show entered commands on screen as you type.
- Output data format.

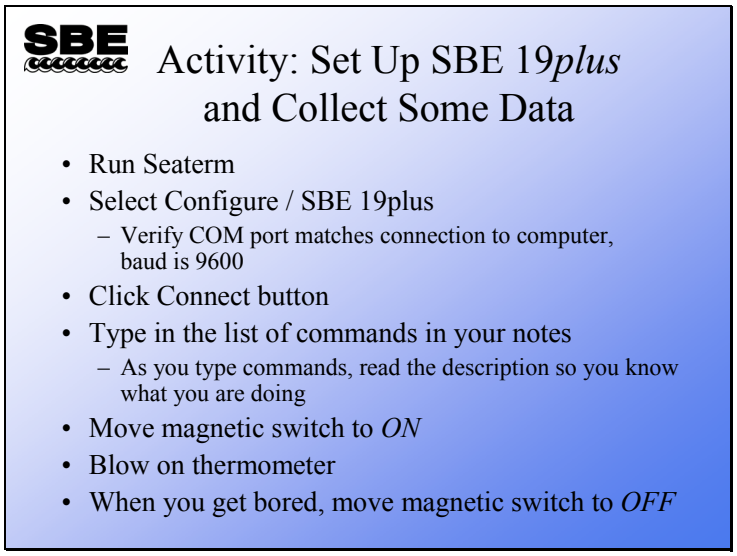
Activity



If you are using a USB to RS-232 converter, you'll need to know what COM port your computer has assigned to the connection. Follow these directions (written for Windows XP Professional) to determine the COM port:

1. Select Start / Control Panel.
2. Select System.
3. Click the Hardware tab.
   A. Click *Device Manager.*
   B. Click *Ports.*
   C. Write down what COM port designation has been assigned to the USB port.

Activity



Click Start -> Programs -> Sea-Bird -> Seaterm

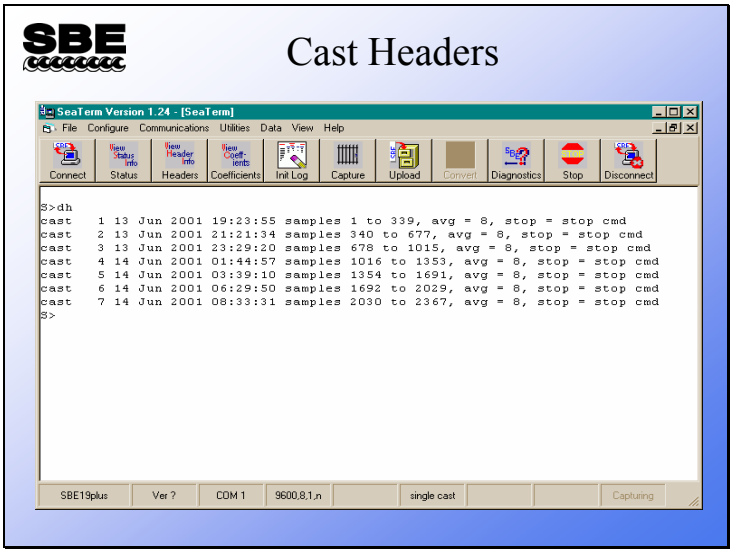
Select SBE 19*plus* from opening dialog

Select Configure -> SBE 19*plus* – verify COM port matches computer connection, baud=9600

Click the *Connect* button

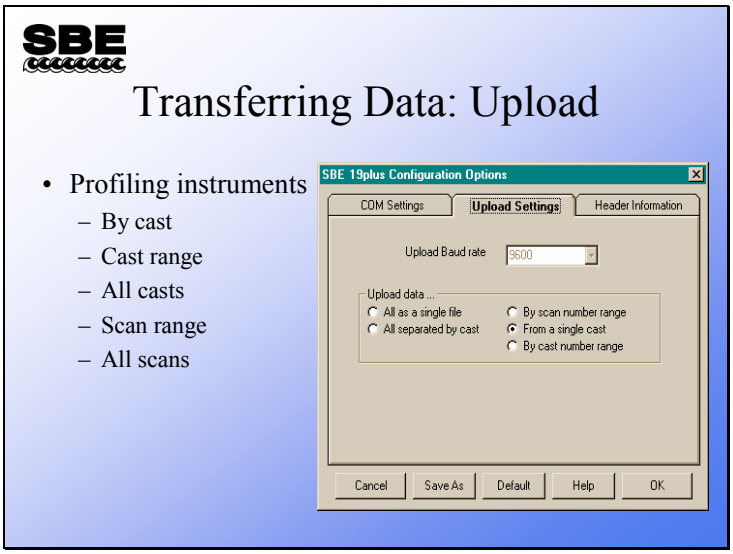
COMMAND	**DESCRIPTION**
MP	Set instrument to profiling mode
BATTERYTYPE=ALKALINE	Instrument has alkaline batteries
VOLT0=N	No auxiliary sensor 0 installed
VOLT1=N	No auxiliary sensor 1 installed
VOLT2=N	No auxiliary sensor 2 installed
VOLT3=N	No auxiliary sensor 3 installed
SBE38=N	No auxiliary temperature sensor installed
GTD=N	No gas tension device installed
PTYPE=1	Strain gauge pressure sensor installed
NAVG=1	Sample at 4 Hz
SAMPLENUMBER=0	Resets memory
IGNORESWITCH=N	Enables magnetic switch
OUTPUTFORMAT=2	Raw data transmitted as decimal numbers
TSR	Request a scan of raw data, conductivity frequency is 2nd
MINCONDFREQ=CCCC	Set pump start frequency to dry cell conductivity frequency (from TSR) + 500
PUMPDELAY=40	Set logging delay to allow time for air to leave the plumbing
OUTPUTFORMAT=0	Raw data transmitted as hexadecimal numbers
DS	Verify setup with status command

Stored Cast Headers



The cast header lists the start date and time, number of scans, number of samples averaged per scan, and reason the cast ended for each cast.

Transferring Stored Data



Data from an internally recording instrument can be transferred to your computer in one of five ways:

By cast: At the start of data transfer, Seaterm prompts for which cast you want.

By cast range: At the start of data transfer, Seaterm prompts for which cast range you want. If header information is to be added to the file, Seaterm prompts for it before uploading each cast.

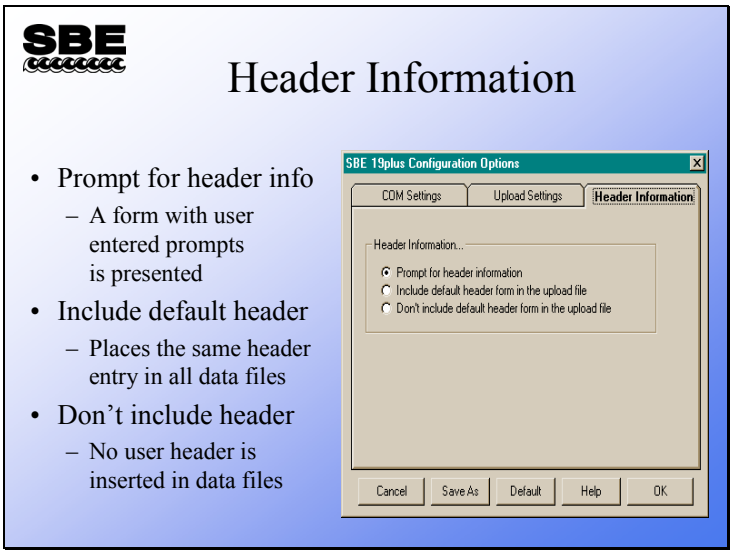
All casts: Seaterm transfers all casts stored in the instrument, placing each cast in a separate file identified by a 3-digit cast number which is appended to the uploaded file name. If appropriate, Seaterm prompts for headers at the start of each cast transfer.

By scan range: At the start of data transfer, Seaterm prompts for which scan range you want. This is useful for instances when data is not arranged in casts or when only part of a cast is desired.

All scans: All scans in the instrument are transferred.

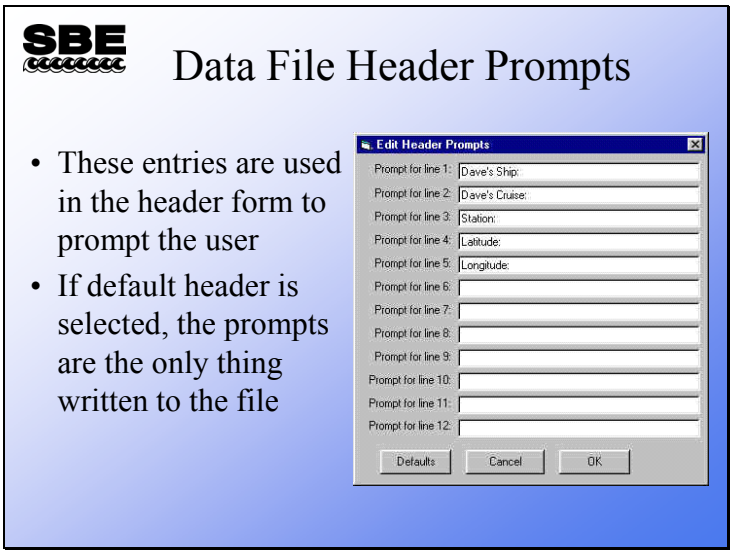
SBE 19s and SBE 25s can transfer data at a faster baud rate than they normally use to communicate. This allows real-time data to be transmitted at a slow baud rate, but data transfer to occur more quickly. When appropriate, the Upload Baud rate selection is enabled.

Data File Headers



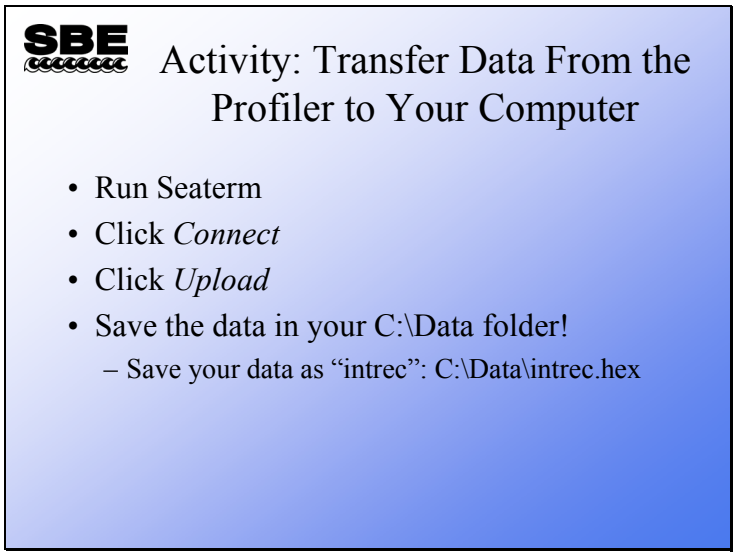
User headers may be placed in uploaded data files. The header is based on user entries in a form with user prompts, or a default header where the same header is placed in every data file. The prompts are entered from the Configure menu: click Configure, Header Form.

Data File Header Prompts

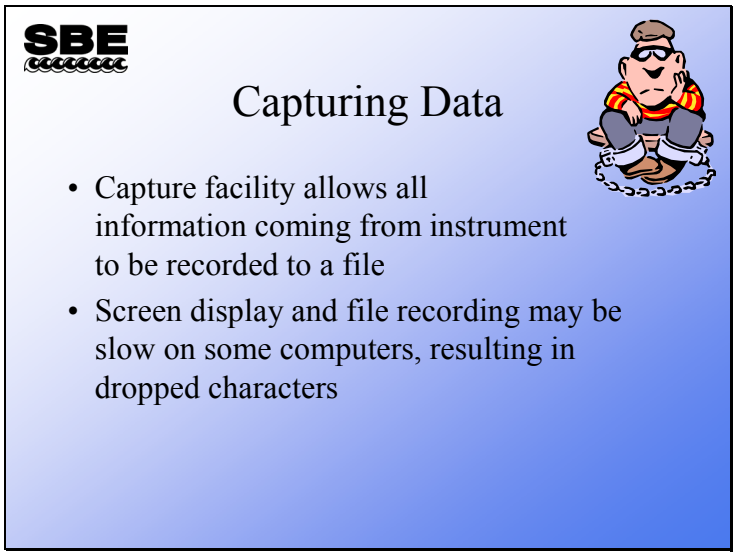


These prompts are used in the header form to guide the user's file annotation. Any information pertinent to the use of the instrument may be included. If *default header* is selected in the Configuration Options dialog box, these are the only entries that will be added to the file's header; the default entries should reflect more complete information.

Activity

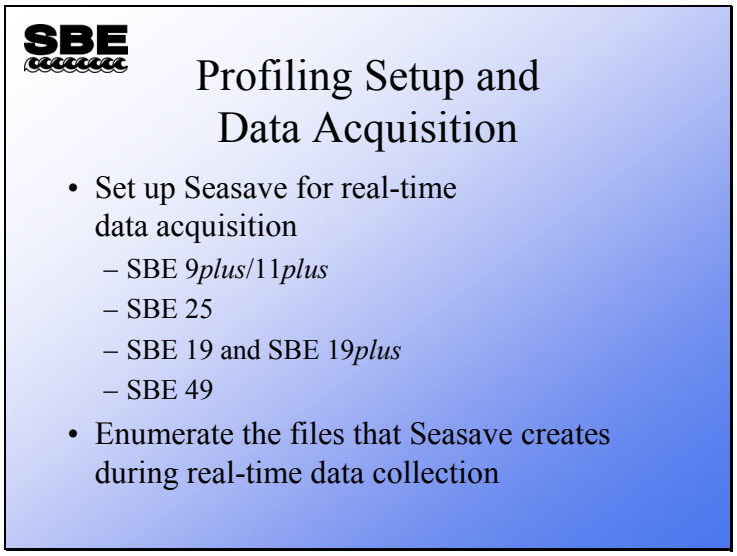

Activity: Transfer Data From the Profiler to Your Computer
• Run Seaterm
• Click *Connect*
• Click *Upload*
• Save the data in your C:\Data folder!
– Save your data as “intrec”: C:\Data\intrec.hex

Seaterm: Capturing ASCII Data



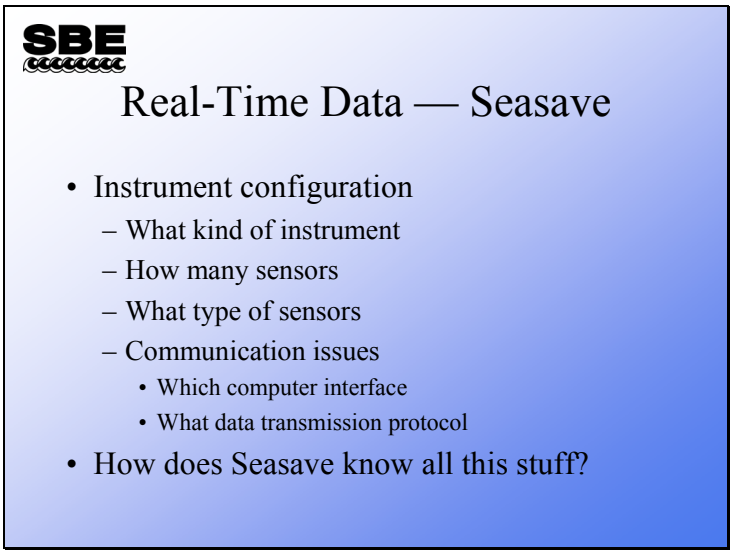
The capture facility allows Seaterm to place all characters received into a file. This is useful for testing instruments, performing diagnostics, or in some cases recording real-time data. Note that there is no testing of data integrity and the act of displaying the characters on the screen while they are being written to a file may cause some characters to be lost.

Seasave: Setup for Real-Time Data Acquisition



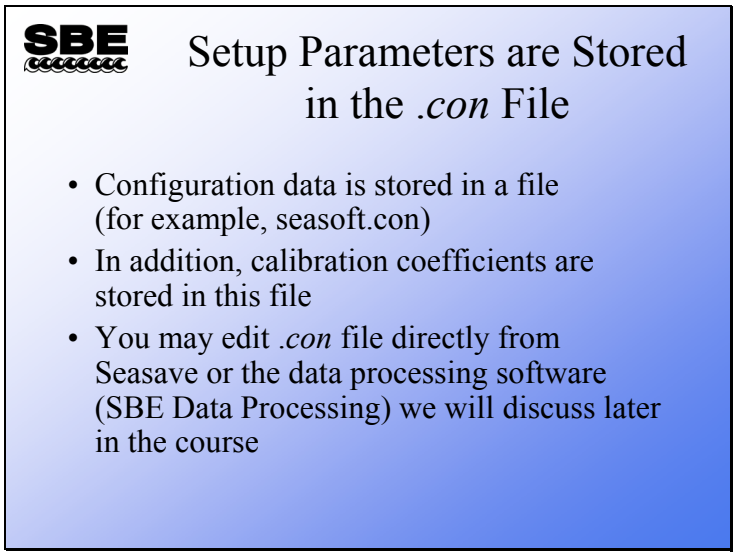
Next, we are going to discuss Seasave, an application that collects real-time data and saves it to a file. We will learn how to set up Seasave and what files are created in the process of data collection.

Seasave: Instrument Configuration



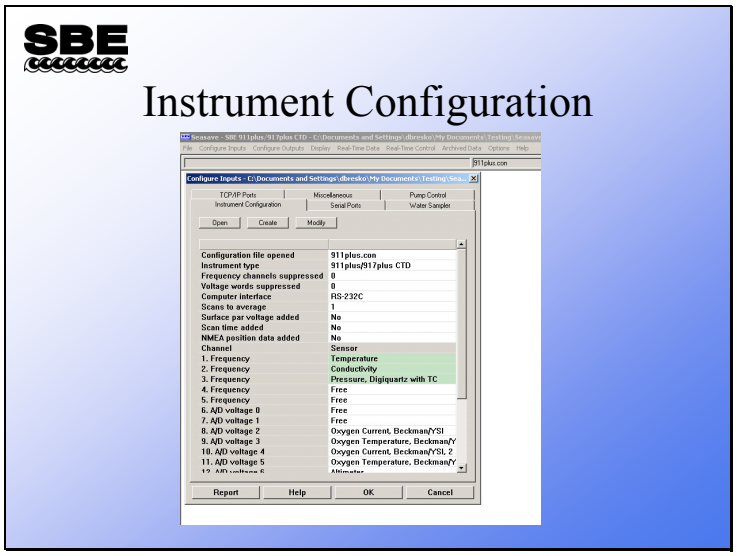
Without this information Seasave is not able to properly process the data stream that is received from an instrument. This is the template for all communications and data processing.

Seasave: *.con* File



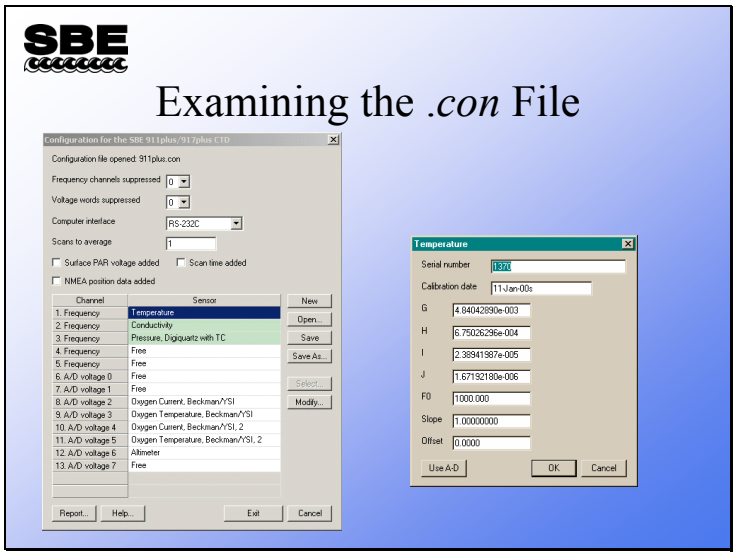
We are beating this topic to death because one of the most common problems people have is mistakes in the .con file. All of Sea-Bird's profiling instruments produce a coded data file. The information to decode this file is found in the .con file. The .con file allows one application to service many instrument types.

Seasave: Selecting a Configuration File



Click the Configure Inputs menu to get the Configure Inputs dialog box; the first tab is the Instrument Configuration tab. From the Instrument Configuration tab, you can open and examine an existing .con file, or create a new .con file.

Seasave: Configuration File Contents



The *.con* file contains information about your instrument configuration and the calibration coefficients for your sensors. For example, you can suppress unused frequency channels; many 9*plus* CTDs only have one temperature and one conductivity sensor. Suppressing 2 frequency channels allows you to collect data from the 9*plus* without 2 frequency channels that will always be zero. Similarly, you can suppress unused voltage channels in pairs (shown as voltage words). You must suppress pairs because of constraints on the binary data format that comes from the 9*plus*. For example, if you have 1 temperature sensor, 1 conductivity sensor, a fluorometer, and an SBE 43 dissolved oxygen sensor, you can suppress 2 frequency channels and 3 voltage words, saving 14 bytes per data scan.

The .con file also has a selection of computer interface, RS-232 or IEEE-488. If your computer is equipped with an IEEE-488 board, you may select IEEE-488. The IEEE-488 communication protocol is faster than the serial port and was more commonly used when computers were slower than those available today.

The 11*plus* can average incoming scans and present the result to your computer. This will also reduce the file space needed to store your data. However, modern computers have large memories, and the loss of resolution in your CTD data makes averaging any more than 2 scans unattractive for most applications.

You may plug a light meter into the 11*plus* and include Surface PAR (photosynthetically active radiation) in your data stream. This is useful for determining percent available PAR as your CTD equipped with a PAR sensor descends into the darkness.

Time and position may be added to the data scans as well. The *Scan time added* check box causes Seasave to append your computer system time to each scan and the NMEA position check box appends a Latitude and Longitude from a GPS receiver that is transmitting NMEA message 0183.

Each data channel can then be assigned a sensor.

Activity

Click Start -> Programs -> Sea-Bird -> SeasaveV7

Click menu item Configure Inputs ->
Create ->
19 Seacat plus CTD
OK

Select:
Strain gauge
0 external voltages
profile mode
1 scan to average

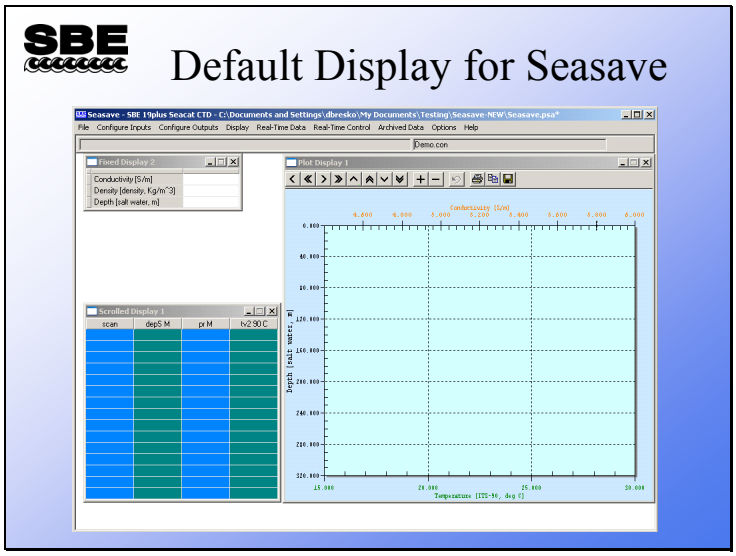
In the Sensor list, click on *Temperature*, click the *Modify* button.
In the dialog that pops up, type the calibration coefficients from the calibration sheet, leave slope as 1.0 and offset as 0.0, click OK.

Click on *Conductivity*, click the *Modify* button.
In the dialog that pops up, type the calibration coefficients from the calibration sheet, leave slope as 1.0 and offset as 0.0, click OK.

Click on *Pressure, Strain Gauge*, click the *Modify* button.
In the dialog that pops up, type the calibration coefficients from the calibration sheet, leave offset as 0.0, click OK.

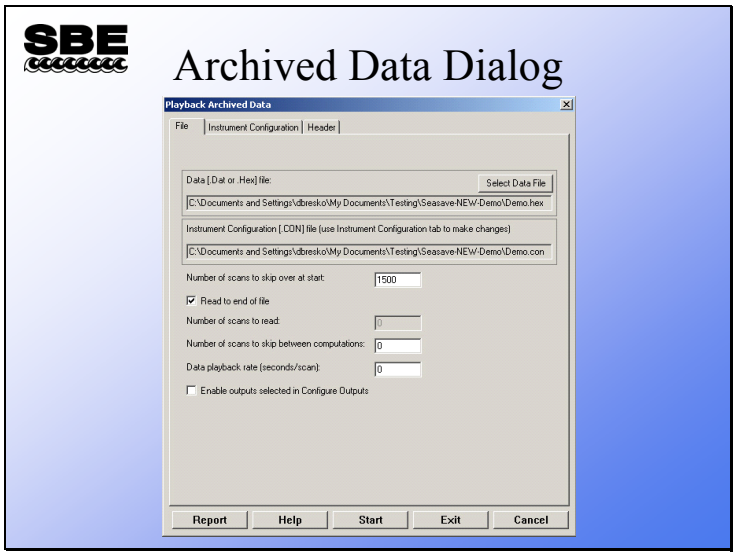
Important! Click *Save As…* and save your file as test.con in your C:\Data directory.

Seasave: Default Display



The slide above has all three data windows visible. The top left window is a fixed display and the bottom left window is a scrolling display. The right window is a multi-axis plot.

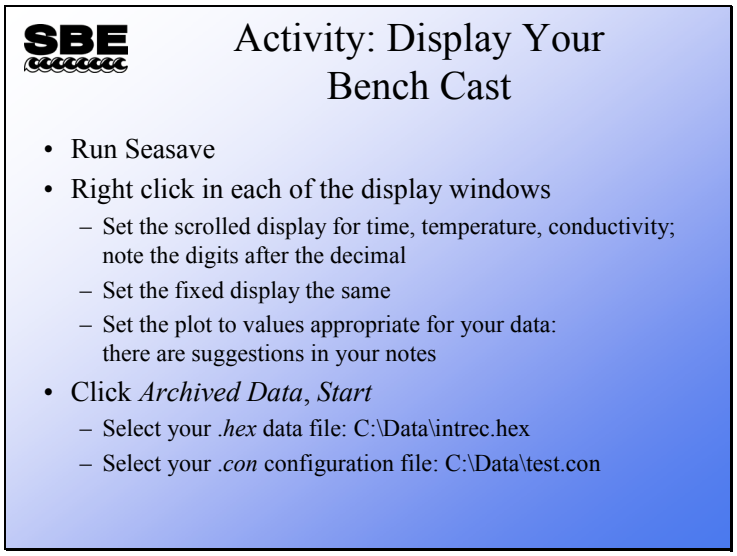
Seasave: Displaying Archived Data



You have the option of skipping data scans at the beginning of the file; this allows you to skip scans collected while the instrument was on deck and going into the water. There is also the option to skip scans when displaying the data; for very long casts this allows you to decimate the data. You can skip 1 or more seconds between scans displayed. You can play back the data at the same rate it was acquired, or you can play it back really fast (set Data playback rate to 0) to generate a plot quickly.

If desired, you can *Enable outputs selected in Configure Outputs*, such as outputs to a serial port, TCP/IP port, shared file, or SBE 14 Remote Display. If enabled, the archived data will be written to / sent to those devices / files as if real-time data was being collected at the designated data playback rate. We'll talk more about Configure Outputs in a few minutes.

Activity



Click Configure Inputs ->
Click Open
Select the .con file you created (test.con) and click Open
Click OK

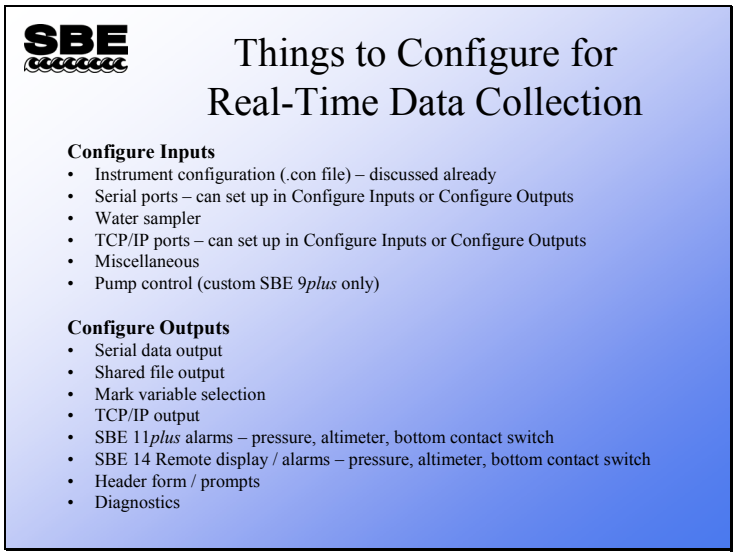
Right click on the scrolled display -> Modify
Click Delete All
With the first row in the table highlighted, double click Time, Elapsed -> seconds
With the second row in the table highlighted, double click Temperature -> ITS-90 -> deg C
With the third row in the table highlighted, double click Conductivity -> S/m
Set the Digits (right of decimal place) to 0 for time, 3 for temperature, and 3 for conductivity
Click OK

Right click on the fixed display -> Modify
Click Delete All
With the first row in the table highlighted, double click Time, Elapsed -> seconds
With the second row in the table highlighted, double click Temperature -> ITS-90 -> deg C
With the third row in the table highlighted, double click Conductivity -> S/m
Set the Digits (right of decimal place) to 0 for time, 3 for temperature, and 3 for conductivity
Click OK

Right click on the plot display -> Modify
Click the Plot Setup tab ->
Set Plot type to Single Y – Multiple X
Set Number of Axes to 3
Click the Y axis tab ->
Click Select Variable button, select Time, Elapsed -> seconds, click OK
Set the axis minimum to 0 and maximum to 600
Click the X-Axis 1 tab
Click Select Variable button, select Temperature -> ITS-90 -> deg C, click OK
Set the axis minimum to 20 and maximum to 25
Click the X-Axis 2 tab
Click Select Variable button, select Conductivity -> S/m, click OK
Set the axis minimum to -0.01 and maximum to 0.01

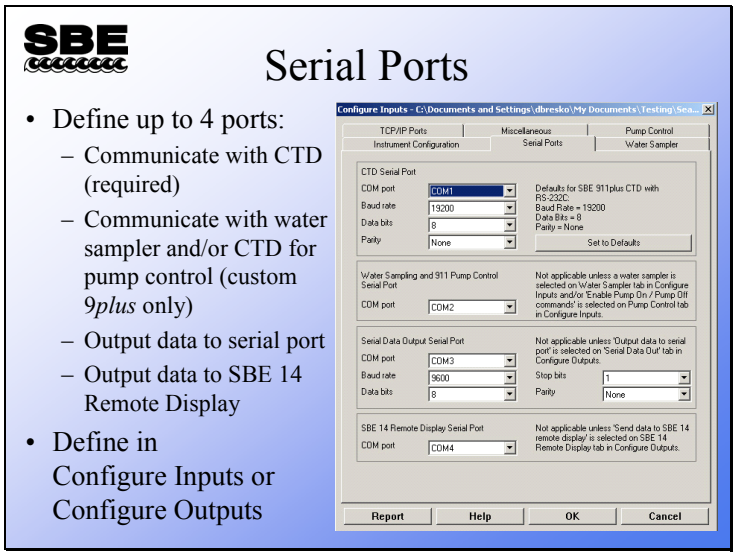
Click OK

Seasave: Configuring Seasave



We'll talk about most of these briefly.

Seasave: Configuring Serial Ports



Entries for CTD Serial Port are always required. The other entries are ignored if the applicable input or output is not enabled.

CTD Serial Port

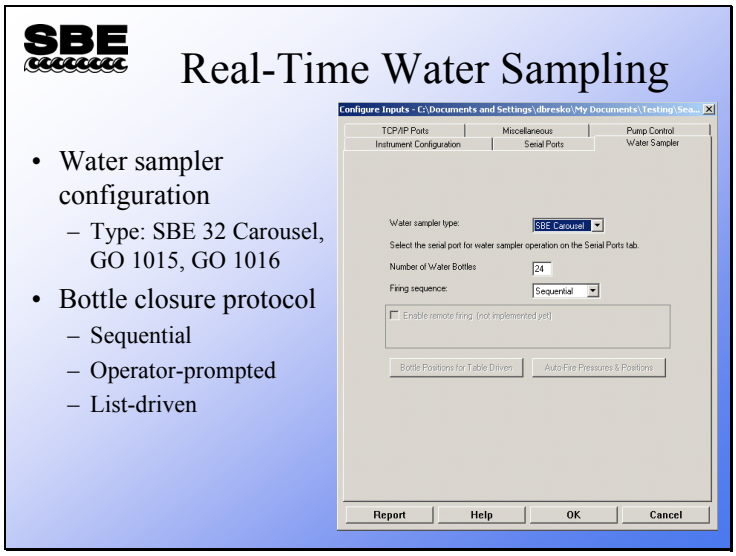
- For the SBE 11*plus* Deck Unit, this is the COM port connected to the *SBE 11 Interface* connector.
- For the SBE 33 or 36 Deck Unit, this is the COM port connected to the *Serial Data* connector

Water Sampler / 911 Pump Control Serial Port

- For the SBE 11*plus* Deck Unit, this is the COM port connected to the *Modem Channel* connector.
- For the SBE 33 Deck Unit, this is the COM port connected to the *Carousel Data* connector.

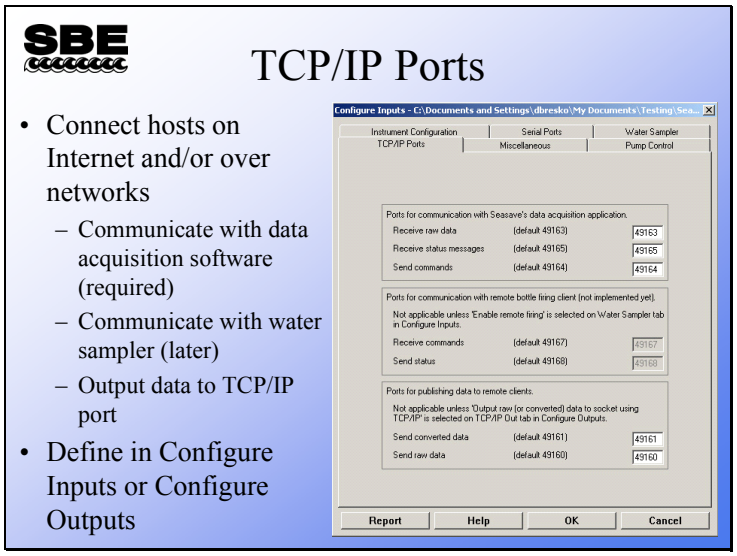
Serial Ports can be defined in Configure Inputs or in Configure Outputs – changes you make in one dialog box are automatically shown in the other.

Seasave: Configuring Water Sampling



Don't forget to select the desired COM port for communication with the water sampler on the Serial Ports tab!

Seasave: Configuring TCP/IP Ports



Entries for ports for communication with Seasave's data acquisition application are always required.

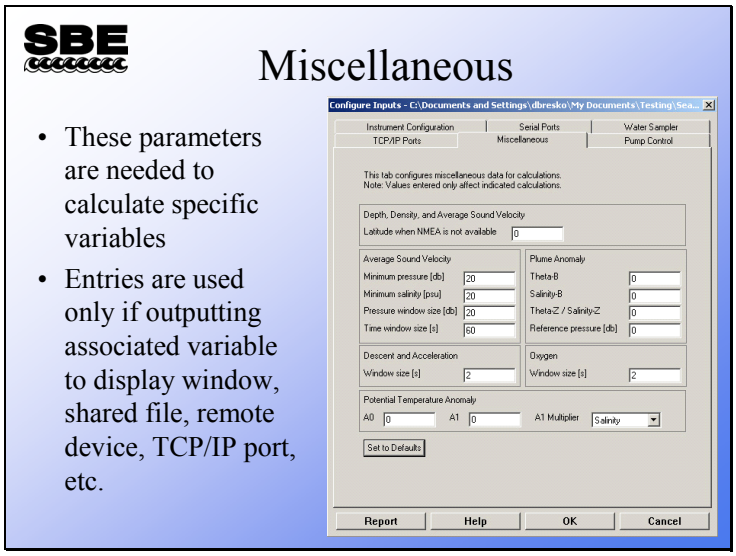
- Seasave is actually 2 applications – Seasave.exe automatically launches SeasaveAcq.exe when data acquisition is commanded to start, and both programs runs simultaneously on the same computer.

Entries for all other ports are ignored if the applicable input or output is not enabled.

Note: The remote bottle firing client will be implemented in a future release of Seasave.

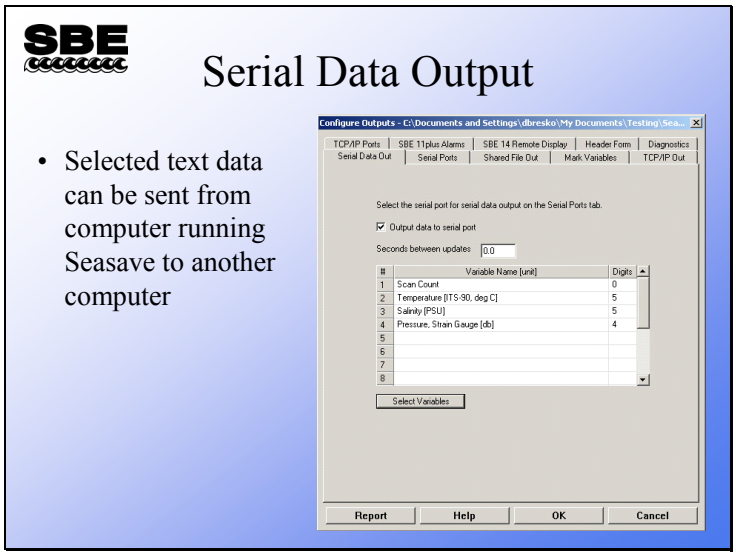
TCP/IP Ports can be defined in Configure Inputs or in Configure Outputs – changes you make in one dialog box are automatically shown in the other.

Seasave: Defining Miscellaneous Parameters



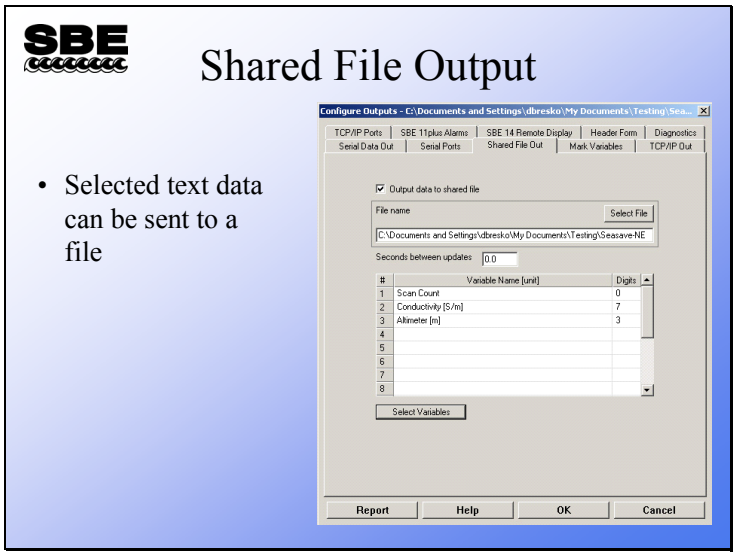
The Miscellaneous tab defines parameters required for output of specific variables. These entries are used only if you are outputting the associated variable to a display window, shared file, remote device, TCP/IP port, etc. For example, if you do not select Oxygen as an output variable for a display window or on any tab in the Configure Outputs dialog box, Seasave ignores the value entered here for Oxygen window size.

Seasave: Configuring Serial Data Output



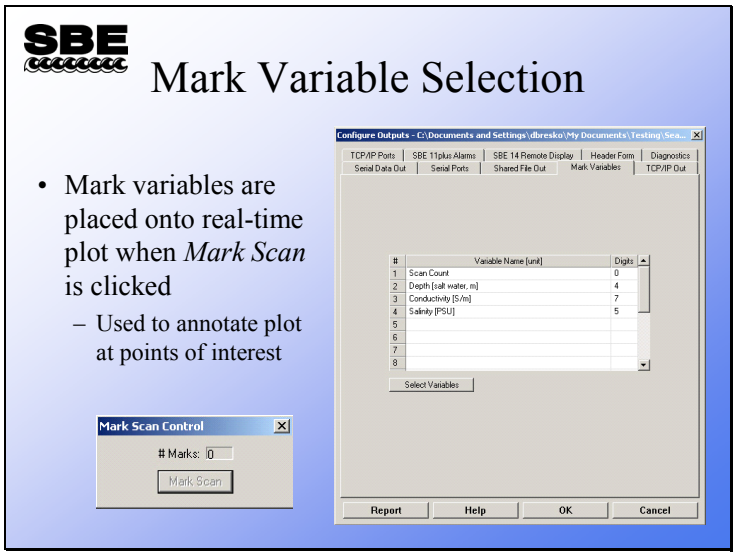
An ASCII stream of data can be sent out a spare serial port on your computer. The data scan contains parameters that you have selected, displayed to the precision you have set.

Seasave: Configuring Shared File Output



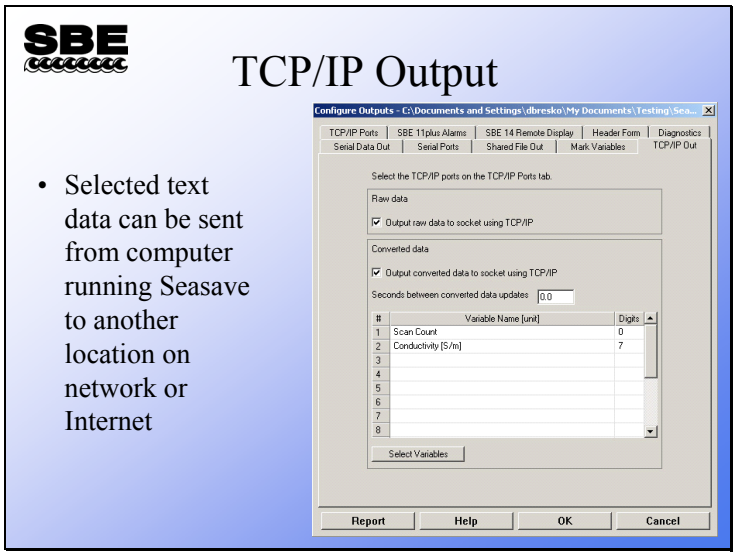
An ASCII stream of data can be sent out to a shared file on a network. The data scan contains parameters that you have selected, displayed to the precision you have set.

Seasave: Configuring Mark Variables



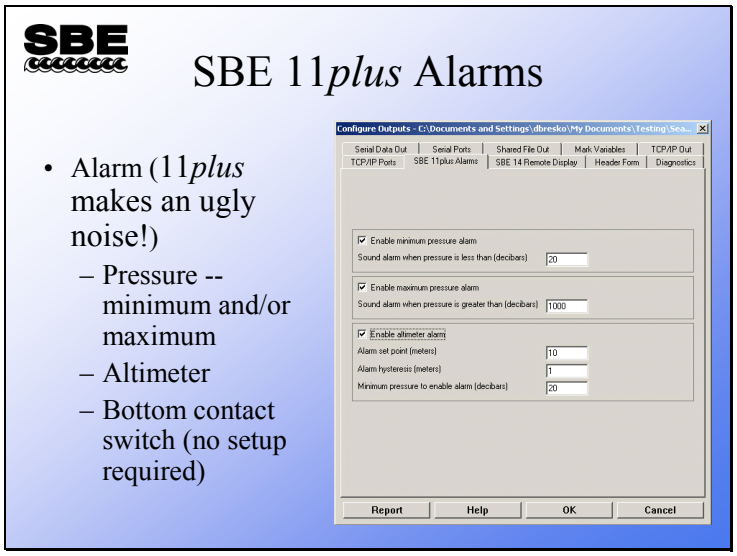
Mark Variables annotate a real-time plot with operator-chosen parameters. When *Mark Scan* is clicked, a line is placed across the plot and the requested variables are written on the line. A file is also created with a *.mrk* extension. This file contains a line for each mark with the selected mark variables.

Seasave: Configuring TCP/IP Output



Data (raw and/or converted data) can be sent out using the TCP/IP ports. For converted data, the data scans contain parameters that you have selected, displayed to the precision you have set.

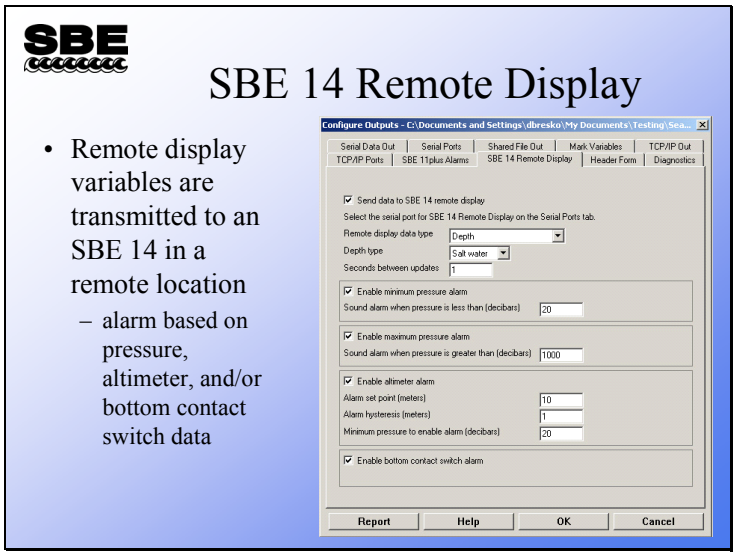
Seasave: Configuring SBE 11*plus* Alarms



The SBE 11*plus* Deck Unit has an alarm that can be set up to operate based on minimum pressure, maximum pressure, data from an altimeter, and/or data from a bottom contact switch.

- The alarm sounds based on minimum pressure, providing a warning that the CTD is nearing the surface.
- The alarm sounds based on maximum pressure, providing a warning that the CTD is deeper than desired.
- The alarm sounds based on the output from an altimeter integrated with the 9*plus* CTD, providing a warning that the CTD is nearing the bottom. This alarm requires a set point (the height above the bottom where it sounds), a hysteresis value (keeps it from going on…off...on...off...on… as the boat rocks), and a minimum pressure to enable (to keep spurious data from setting off the alarm, like when the instrument package goes into the water).
- The alarm also sounds based on the output from a bottom contact switch integrated with the 9*plus* CTD, providing a warning that the CTD is nearing the bottom. No setup is required for the alarm to operate based on bottom contact switch data.

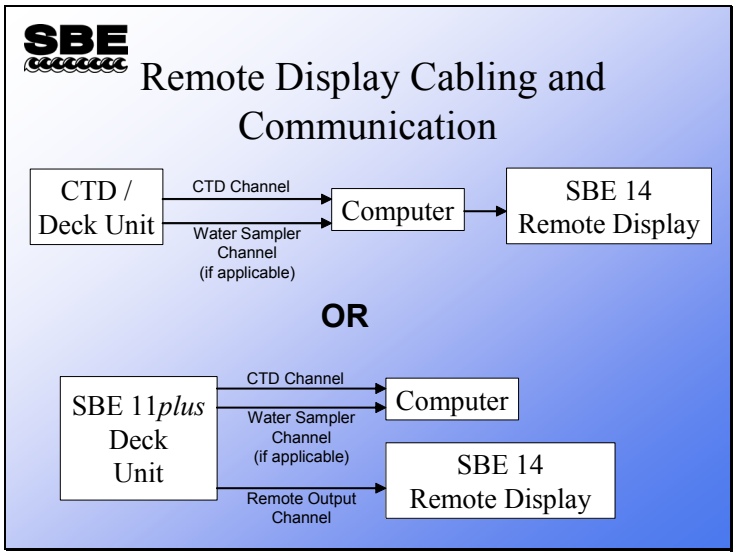
Seasave: Configuring SBE 14 Remote Display



The SBE 14 remote display receives pressure, depth, and/or altimeter data and displays it on a large, liquid-crystal display. The SBE 14 may be placed anywhere it is useful, for example: in the winch dog house, in the wet lab, on the bridge, or in the chief scientist's stateroom to name just a few. The SBE 14 also has an audible alarm that may be triggered by minimum pressure, maximum pressure, altimeter data, and/or bottom contact switch data.

Setup of the alarm parameters is similar to that for an SBE 11*plus* with one exception. If you want an alarm based on bottom contact switch data, you must enable it on this tab.

Cabling a Remote Display

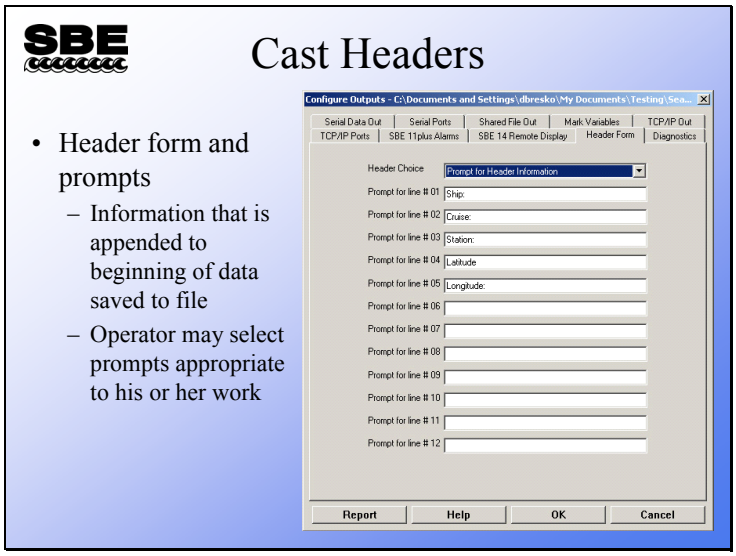


The SBE 14 remote display can be cabled to your system in one of two ways:

- Connected to one of the com ports on your PC (applicable to use of the SBE 14 with any of our CTDs/Deck Units, including the SBE 11*plus*), or
- Connected directly to the SBE 11*plus* – If connected this way, setup of the Remote Display is not done in Seasave; see the 11*plus* manual.

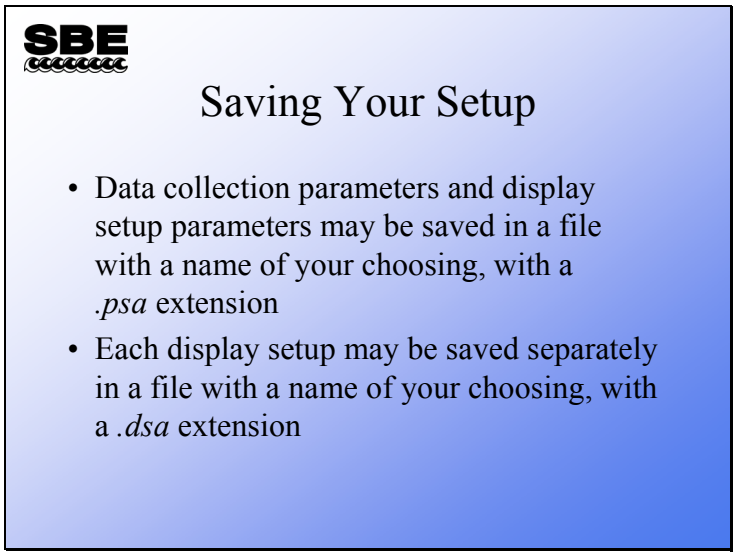
Note that the deck unit requires either a com port or a GPIB port (GPIB port only available for 11*plus*), and the water sampler requires a com port. If the remote display is connected to the computer, it requires an additional com port.

Seasave: Configuring Cast Headers



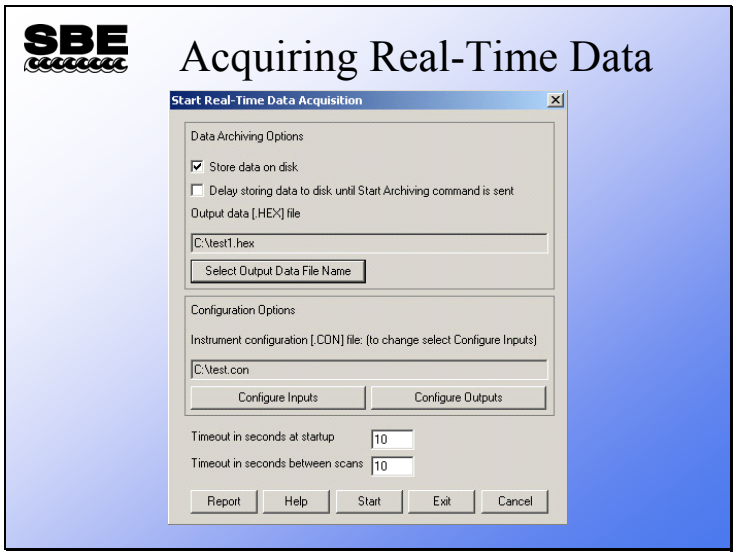
User headers allow the CTD operator to add annotation to the data file. This can take the form of an operator filled out table or a set of default text. The header form may be skipped altogether if desired.

Seasave: Saving Your Setup



Setup files are handy for different instrument types or for pre-deployment instrument checkout *vs.* deployment display. For example, you might use fixed display or scrolled display for pre-deployment check out and then switch to a full screen plot for the cast.

Seasave: Acquiring Real-Time Data

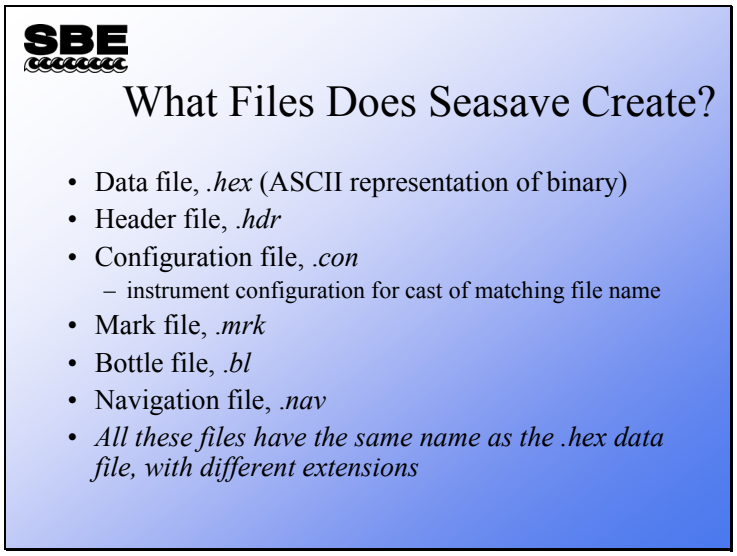


Click the Real-Time Data menu to get the Start Real-Time Data Acquisition dialog box.

Acquiring real-time data requires the operator to select a .con file, and decide whether or not to store data to a file and what the name of the file should be. Clicking *Start* initializes the CTD/Deck Unit, sends operator choices regarding channel suppression and averaging, and begins displaying data.

Note: Don't forget to configure the Com port(s) in Configure Inputs or Configure Outputs before you click *Start*!

Seasave: File Types



If you select *store on disk* for a file name of *MyFile*, Seasave creates the following files:

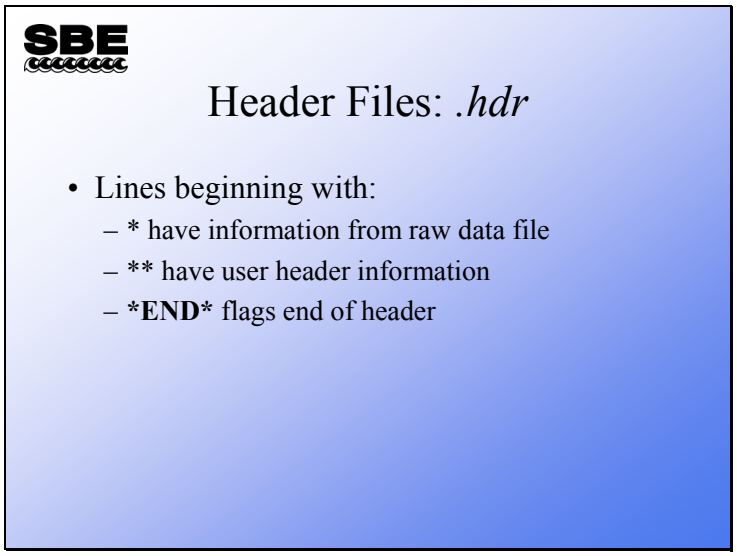
- *MyFile.hex* has an ASCII (text) representation of binary data in hexadecimal format plus the header in ASCII (text) at the beginning of the file.

AND

- *MyFile.hdr* has the header information only, in ASCII.
- *MyFile.con* has the instrument configuration and calibration coefficients.
- *MyFile.mrk* has data scans with the chosen mark file variables.
- *MyFile.bl* has scans that were collected when the bottle closure confirm was received (if a water sampler is used).
- *MyFile.nav* has navigational information collected during the cast

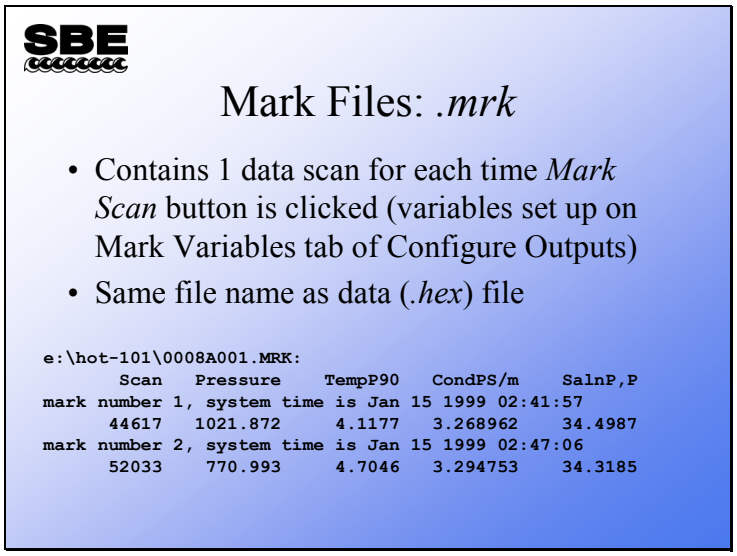
Note: Older versions (<6.0) of Seasave created a binary data file (.dat) instead of a .hex file during SBE 911*plus* data acquisition. *MyFile.dat* had binary data plus the header in ASCII (text) at the beginning of the file. The rest of the output files were the same as the current version of Seasave.

Seasave: Header Files

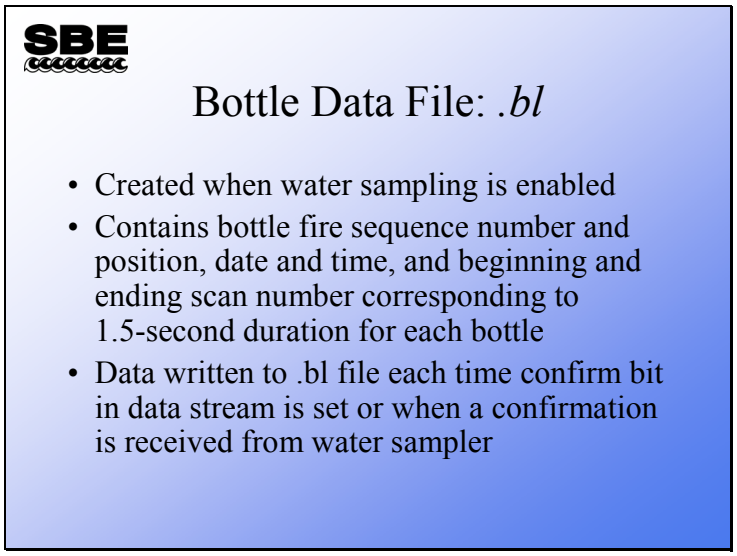



```
* Sea-Bird SBE 9 Raw Data File:
* FileName = H:\tests\USERS\mikev\Tau Test 2.hex
* Software Version Seasave Win32 v%s
* Temperature SN = 4022
* Conductivity SN = 4022
* Number of Bytes Per Scan = 14
* Number of Voltage Words = 0
* System UpLoad Time = Jun 11 2001 09:51:47
** Ship: RV TestBath
** Cruise:  Tau test
** Station:    Bellevue WA
** 11 Jun 01 bath 0 Tau Test with 19plus #2
*END*
```

Seasave: Mark Files

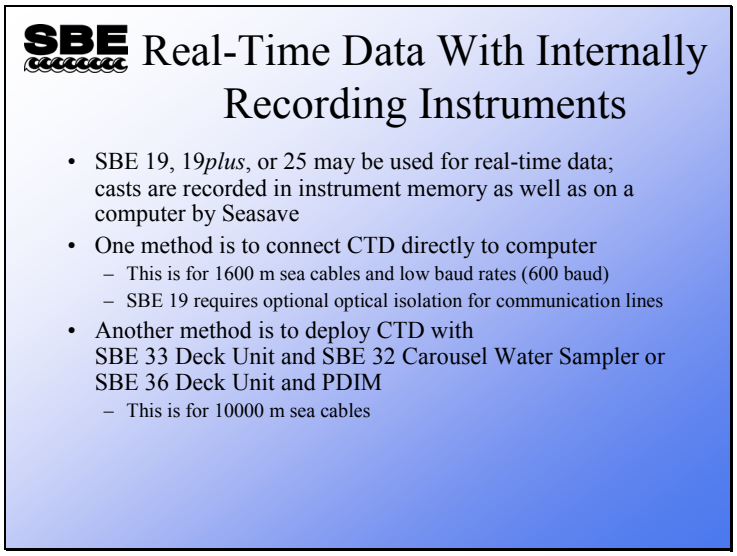


Seasave: Bottle Data Files



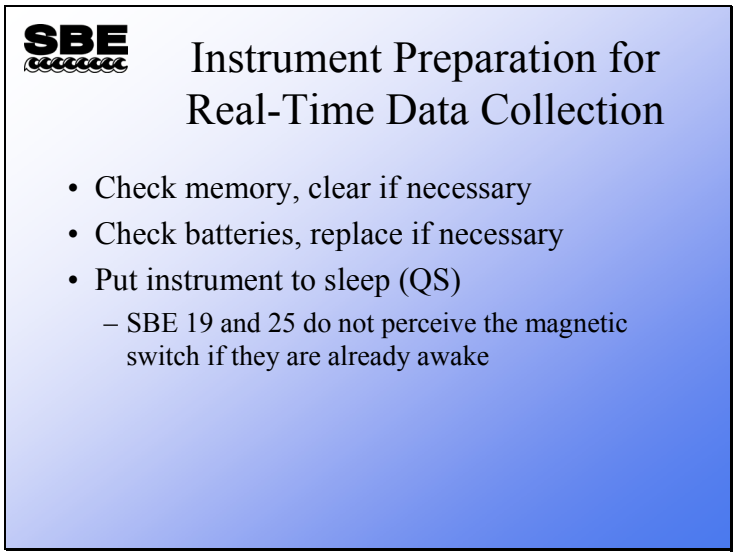
Whenever a bottle confirmation is received by Seasave from either the confirm status bit or via the modem port, a line is written to the output file with a .bl extension. This contains the bottle firing sequence number, bottle position, date, time, and beginning and ending scan number for the fired bottle. It is used in data processing to build up a larger file of data parameters collected while the water sampler was being closed.

Using Internally Recording Instruments for Real-Time Applications

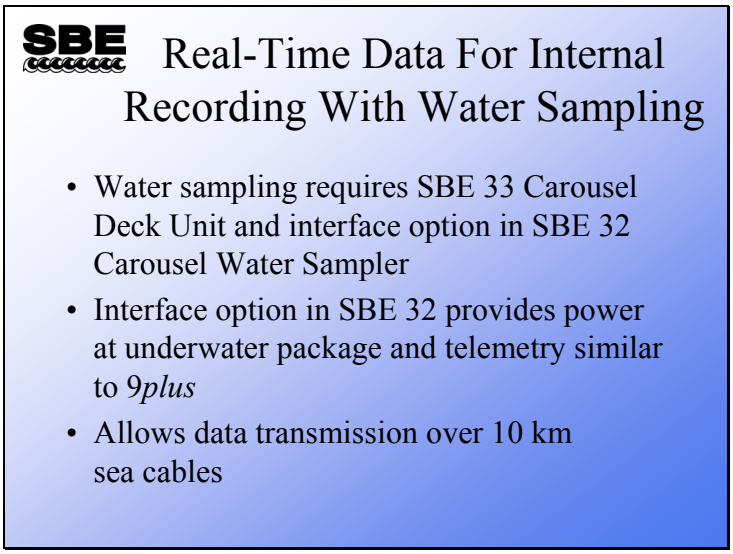


SBE 19s may be outfitted with high power cable drivers and optical isolation for transmitting real-time data. The SBE 19*plus* and 25 come standard with this equipment. With the addition of a Deck Unit and associated underwater equipment listed above, the data telemetry is the same as discussed for the SBE 911*plus*.

Instrument Preparation for Real-Time Data Collection

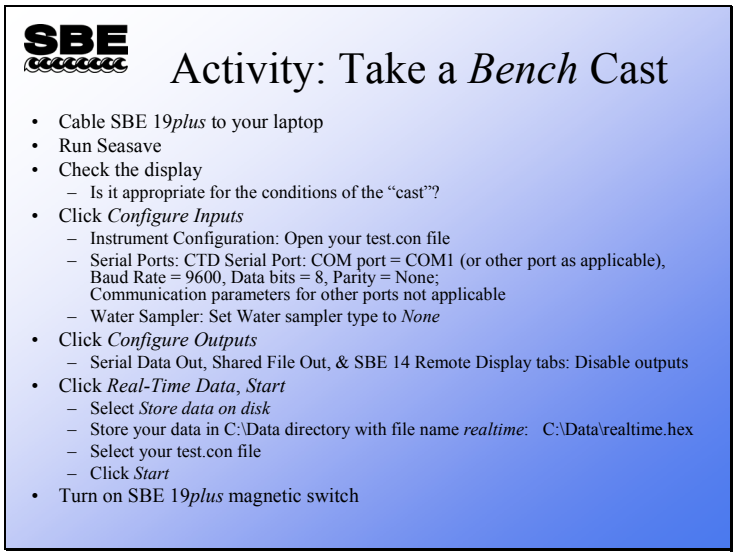


Water Sampling with Internally Recording Instruments



The SBE 19, 19*plus*, and 25 can be equipped with water sampling equipment. The SBE 32 Carousel and SBE 33 Carousel Deck Unit provide power and telemetry for the CTD very similar to the 11*plus*/9*plus* setup. In addition to water sampling, this equipment allows data telemetry over 10 km of sea cable and supplies more than enough power for the CTD and auxiliary sensors.

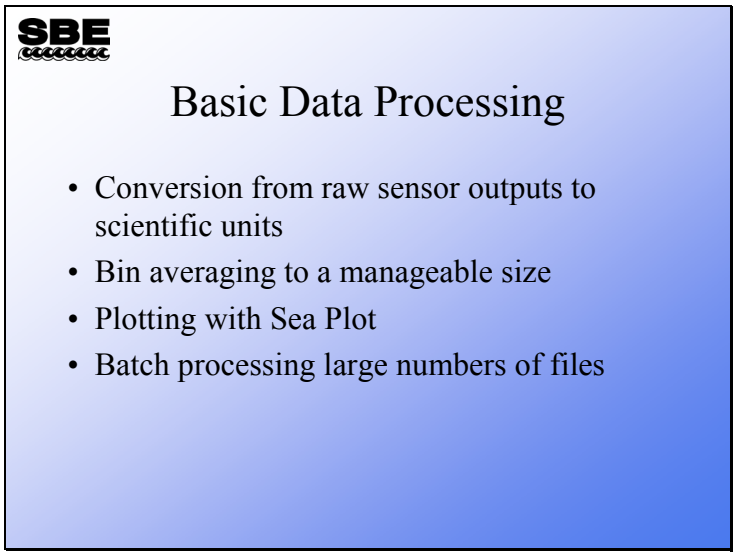
Activity


Activity: Take a *Bench* Cast
- Cable SBE 19*plus* to your laptop
- Run Seasave
- Check the display
  - Is it appropriate for the conditions of the "cast"?
- Click *Configure Inputs*
  - Instrument Configuration: Open your test.con file
  - Serial Ports: CTD Serial Port: COM port = COM1 (or other port as applicable), Baud Rate = 9600, Data bits = 8, Parity = None; Communication parameters for other ports not applicable
  - Water Sampler: Set Water sampler type to *None*
- Click *Configure Outputs*
  - Serial Data Out, Shared File Out, & SBE 14 Remote Display tabs: Disable outputs
- Click *Real-Time Data*, *Start*
  - Select *Store data on disk*
  - Store your data in C:\Data directory with file name *realtime*: C:\Data\realtime.hex
  - Select your test.con file
  - Click *Start*
- Turn on SBE 19*plus* magnetic switch

Module 3

Basic Data Processing

Overview

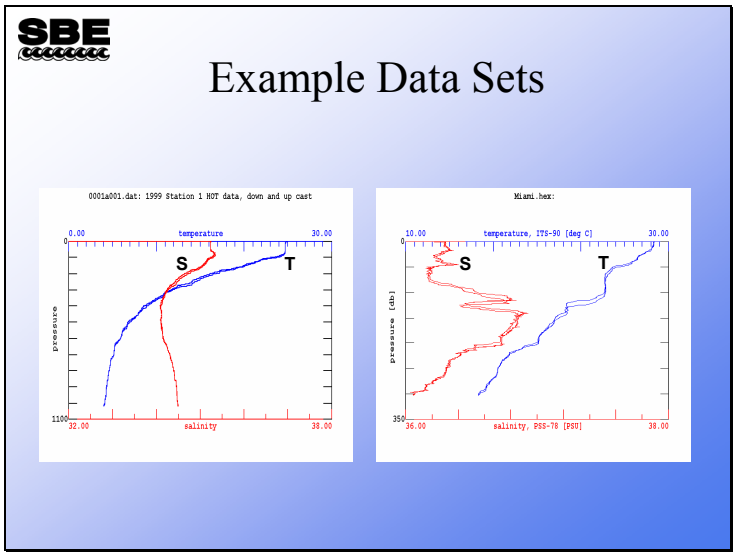


In this module we will cover the data processing basics, no fancy stuff. With this information you can go from raw data file to something you can print or plot.

When we finish this module you should be able to:

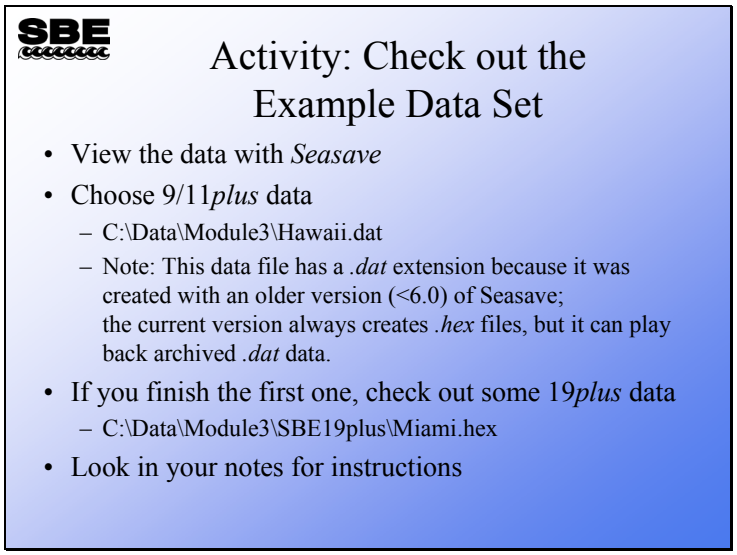
- Run *Data Conversion* and convert your raw data to scientific units.
- Run *Bin Average* to reduce your data set, producing data at even depth values.
- Run *Sea Plot* to display your work.
- Process large numbers of data files by making script files.

Basic Data Processing: Example Data



Here are Seasave plots of some data collected on Hawaii Ocean Time-series cruise 101 and a cruise between Miami and Bimini on a RSMAS vessel.

Activity: View the Example Data



Run Seasave

Set up the plot - right click on the plot and select *Modify*:
For the SBE 9/11*plus* data:
Y axis: Pressure 0 to 1200 decibars
X axis: Temperature 0 to 30 degrees C
X axis: Salinity 34 to 36 PSU
Click OK.

Click the menu *Archived Data -> Start:*
Click *Select Data File*:
Select C:\Data\Module3\Hawaii.dat and click Open.
Seasave asks if you want to change .con file to C:\Data\Module3\Hawaii.con, click Yes.
Click *Start*.

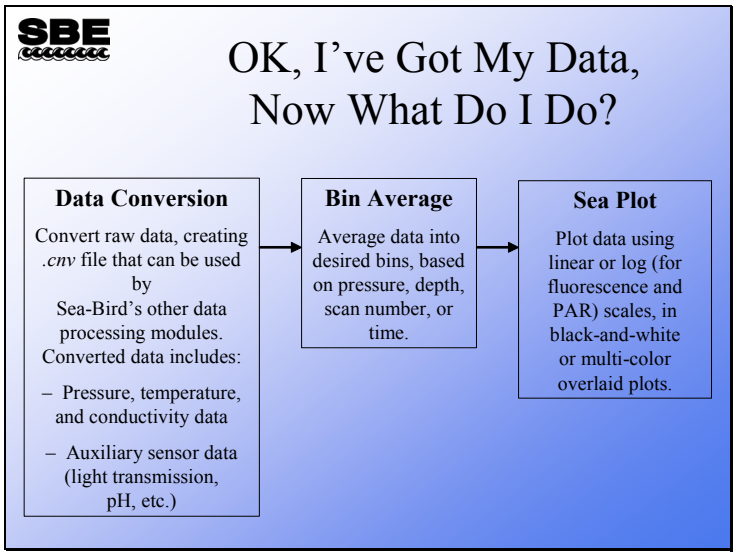
Click the menu *Archived Data* -> *No Wait*

If you have time, plot SBE 19*plus* data:

Y axis: Pressure 0 to 350 decibars
X axis: Temperature 10 to 30 degrees C
X axis: Salinity 36 to 38 PSU

C:\Data\Module3\SBE19plus\Miami.hex
C:\Data\Module3\SBE19plus\Miami.con

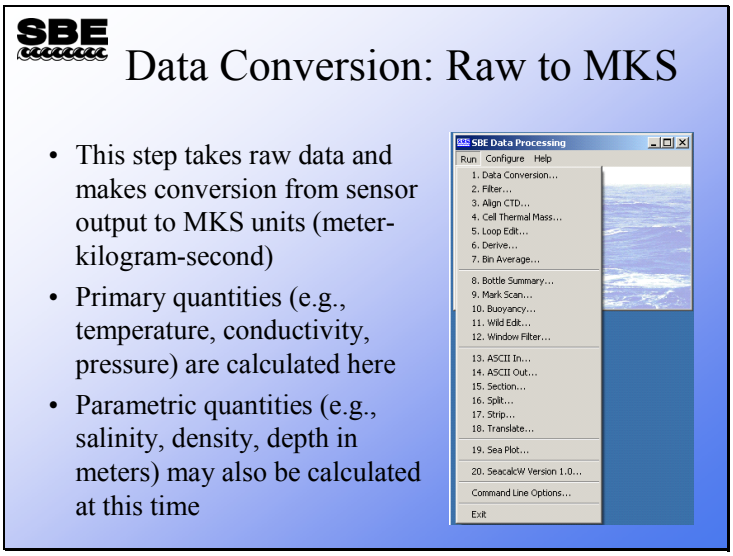
Data Processing: Flow Chart



Data processing involves operating on your raw data (which came from the sensors attached to the instrument) to convert it from the sensor outputs to scientific units, calculate any additional oceanographic parameters of interest, and reduce the data set to a tractable size. It is always the best practice to archive your raw data, because there is no going backwards once you have processed it. Should you discover calibration errors, omit necessary parameters, or make processing errors, it is imperative to return to your raw data set.

Sea-Bird's data processing program, SBE Data Processing, includes a number of modules for processing data; just three are listed above.

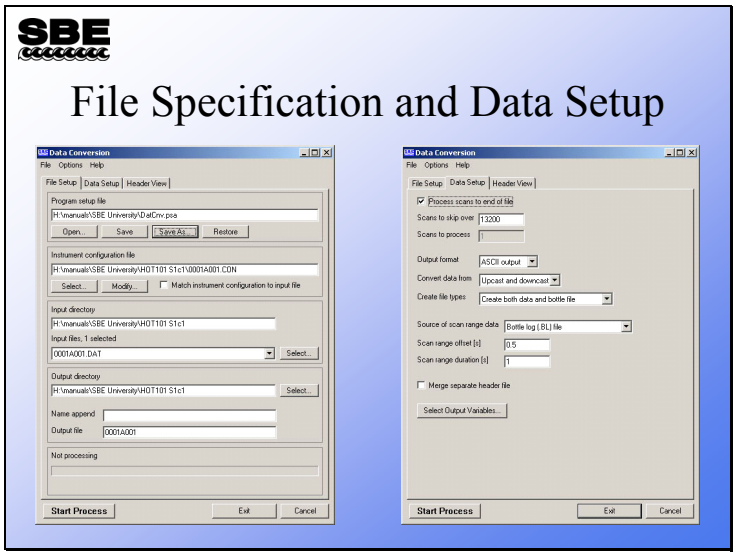
Data Processing: Conversion to Scientific Units



For the basics, we will concern ourselves with Data Conversion and Bin Averaging. Data conversion is the first step.

Data Conversion takes your raw data (.dat or .hex) file and, with the information contained in the .con file, converts it to scientific units. The form the converted data takes is set up in the SBE Data Processing-Win32 Data Conversion dialog. In addition to quantities like temperature and conductivity, parameters that are calculated from these, such as salinity and density, are also available. If you plan to do more advanced processing of your data, you should wait until the advanced processing is complete before calculating parameters derived from the measured parameters.

Data Conversion: File Specification



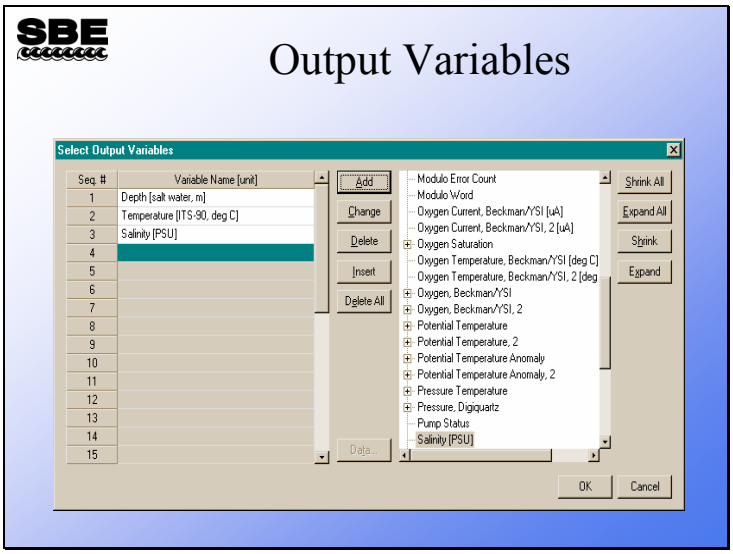
The program setup (.psa) file contains information regarding how the program was set up the last time you used it. This relieves you of the task of choosing the variables and other processing options. In addition, if you have more than one preferred processing protocol, you can store them as separate .psa files. As always, you must select the appropriate .con file for your instrument. You can select multiple files for processing; a separate .cnv file will be created for each file that is processed.

You can process all or part of the data file and skip the beginning (during the time you were checking your instrument before the cast). You can convert the whole cast or just the downcast. If you collected water samples, you can generate a file containing some CTD scans that were collected while the water bottle was being closed. The means of determining where these scans should come from are:

- For the 9*plus* with a G.O. 1015 water sampler, the data stream is marked with a status bit when the bottle closure occurs.
- For internally recording instruments with an AFM, the file uploaded from the AFM (an *.afm* file) can be used.
- A *.bsr* file can be made from a *.mrk* file (collected while running Seasave) with the Mark Scan module.
- If using an SBE 32 Carousel, Seasave writes a *.bl* file that contains the information required.

Once you have settled on the source of information for indicating bottle closure times, you have to select the amount of data to be included in the file for each closure. *Scan range offset* is how far back Data Conversion looks in your data stream in seconds and *Scan range duration* is how long it looks, again in seconds. For example, an offset of -5 seconds and duration of 10 seconds means you will get 5 seconds of data before the bottle closure and 5 seconds after the closure.

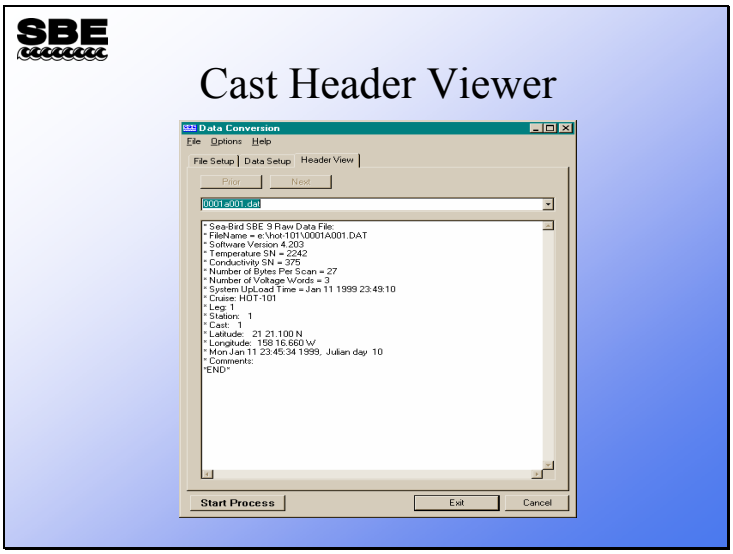
Data Conversion: Output Variable Choices



The output variables dialog allows you to select a table of items that will be calculated and the order in which they will be calculated.

Note that the list on the right reflects the information in the selected .con file – only data measured by the sensors indicated in the .con file, and data that can be calculated from those measurements, are available for output.

Data Conversion: Cast Headers



The header view can reassure you that you are working with the instrumentation you think you are.

Data Conversion: File Headers Revealed

What's a Header?

- Header is placed at the beginning of each data file
  - Header for internally recorded data is written when the data is uploaded from the instrument
  - Header for real-time data is written before the data is recorded
  - These lines are preceded with an *
- Operator comments are added to the header; these lines are preceded with an **
- Headers are updated each time data in the file is manipulated
  - Update contains information relevant to how the data was manipulated
  - These lines are preceded with an #

```
* Sea-Bird SBE 9 Raw Data File:
* FileName = H:\tests\USERS\mikev\Tau Test 2.hex
* Software Version Seasave Win32 v%s
* Temperature SN = 4022
* Conductivity SN = 4022
* Number of Bytes Per Scan = 14
* Number of Voltage Words = 0
* System UpLoad Time = Jun 11 2001 09:51:47
** Ship: RV TestBath
** Cruise:  Tau test
** Station:    Bellevue WA
** 11 Jun 01 bath 0 Tau Test with 19plus #2
# nquan = 3
# nvalues = 2596
# units = specified
# name 0 = timeS: Time, Elapsed [seconds]
# name 1 = tv290C: Temperature [ITS-90, deg C]
# name 2 = flag:  0.000e+00
# span 0 =      0.000,    648.750
# span 1 =     1.7905,     6.5876
# span 2 = 0.0000e+00, 0.0000e+00
# interval = seconds: 0.25
# start_time = Jun 11 2001 09:51:47
# bad_flag = -9.990e-29
# sensor 0 = Frequency 0  temperature
# sensor 1 = Frequency 1  conductivity, 4022, 25-Apr-01, cpcor = -9.5700e-08
# sensor 2 = Frequency 1  conductivity
# sensor 3 = Pressure Voltage
# datcnv_date = Jun 11 2001 10:39:01, 1.00
# datcnv_in = H:\SBE University\data\19p tau test\Tau Test 2.hex H:\SBE University\data\19p tau
test\4022.con
# datcnv_skipover = 0
# file_type = ascii
*END*
```

Data Conversion: Output File Format

Data Conversion Output, *.cnv*

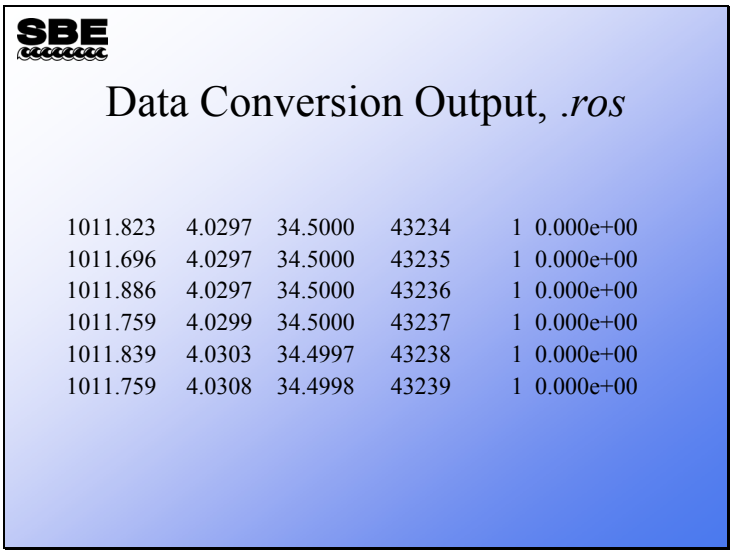
```
# datcnv_date = Jun 25 2001 10:21:54, 5.2
# datcnv_in = HOT101\0001a001.dat HOT101\S1C1\0001a001.con
# datcnv_skipover = 12000
# file_type = ascii
*END*
    10.115   24.7800   35.2446  0.000e+00
    10.178   24.7799   35.2442  0.000e+00
    10.170   24.7798   35.2443  0.000e+00
    10.115   24.7799   35.2444  0.000e+00
```

P (db)	T (°C)	S (PSU)	Error flag

```
* Sea-Bird SBE 9 Raw Data File:
* FileName = D:34-8.DAT
* Software Version 4.0.b.g
* Temperature SN = 1123
* Conductivity SN = 915
* Pressure SN = 43440
* Number of Bytes Per Scan = 15
* System UpLoad Time = January 24, 1992  3:39:09 pm
* Ship:     R/V Poseidon
* Cruise:   189-1a
* Station:  34
* Cast:     8
* Latitude: 35 22.00' N
* Longitude:12 43.36' W
* Second set of CTD trials, station 34 cast 8, SBE Mk3 Mk5a Mk5b probably no FSI trial.
# nquan = 5
# nvalues = 77205
# units = metric
# name 0 = depS: depth, salt water [m]
# name 1 = t068: temperature, IPTS-68 [deg C]
# name 2 = c0S/m: conductivity [S/m]
# name 3 = sal00: salinity, PSS-78 [PSU]
# name 4 = flag:  0.000e+00
# span 0 = 1.519, 3555.084
# span 1 = 2.4822, 17.1124
# span 2 = 3.257845, 4.669567
# span 3 = 34.9097, 36.4804
# span 4 = 0.0000e+00, 0.0000e+00
# interval = seconds: 0.0416667
# start_time = Jan 24 1992 15:39:09
# bad_flag = -9.990e-29
# sensor 0 = Frequency  0  temperature, 1123
# sensor 1 = Frequency  1  conductivity, 915, cpcor = -9.5700e-08
# sensor 2 = Frequency  2  pressure, 43440
# sensor 3 = Extrnl Volt  0  oxygen, current, 130259
# sensor 4 = Extrnl Volt  1  oxygen, temperature, 130259
# datcnv_date = Jun 22 2001 16:19:48, 4.249
# datcnv_in = 34-8.DAT 34-8.CON
# datcnv_skipover = 0
# file_type = ascii
*END*
     1.636   16.9770   4.654863   36.4699  0.000e+00
     1.691   16.9784   4.655062   36.4703  0.000e+00
```

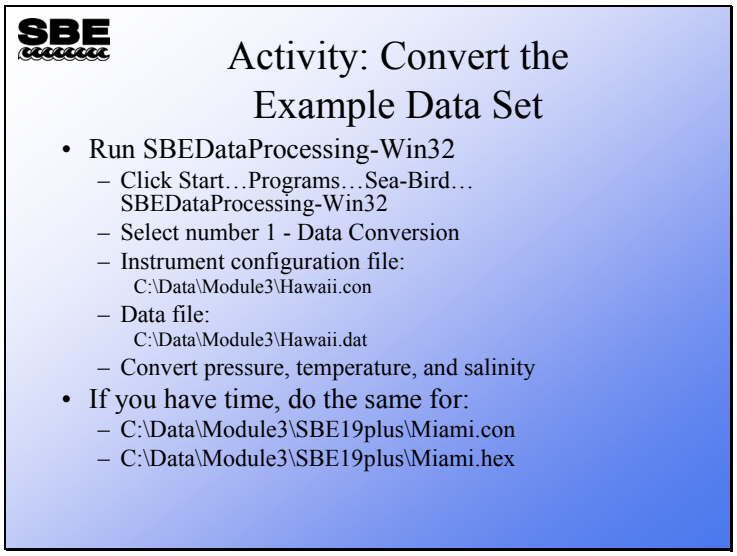
Selected output variables / headings for columns of data below (error flag column added automatically by Data Conversion)

Data Conversion: Water Sampler Output File Format



The data conversion process also writes a file with data collected while water bottles were being closed. You choose the time window of data you want written to the file. For example, you might select to have all scans collected starting 5 seconds before the bottle closes and ending 5 seconds after the bottle closure written to the file. We will discuss the use of this data in correction of CTD conductivity data in the advanced data processing topics.

Activity



Click Start -> Programs -> Sea-Bird -> SBEDataProcessing-Win32
Click Run -> Data Conversion

Click Select for the Instrument configuration file, and select C:\Data\Module3\Hawaii.con
Click Select for Input files, and select C:\Data\Module3\Hawaii.dat

Click the Data Setup tab:

Process to the end of the file
Skip 0 scans
Select output format ascii
Convert data from upcast and downcast
Create .cnv file only

Click the Select Output Variables button

Click on the first Variable Name. Select Pressure, Digiquartz ->db. Click Add or Change
Click on the second Variable Name. Select Temperature -> ITS90 -> deg C. Click Add or Change
Click on the third Variable Name. Select Salinity. Click Add or Change
Click OK

Click the File Setup tab, and save Program setup file as C:\Data\Module3\HawaiiDatCnv.psa
Click Start Process
Open the .cnv file in Notepad or Wordpad and take a look at the header and data.

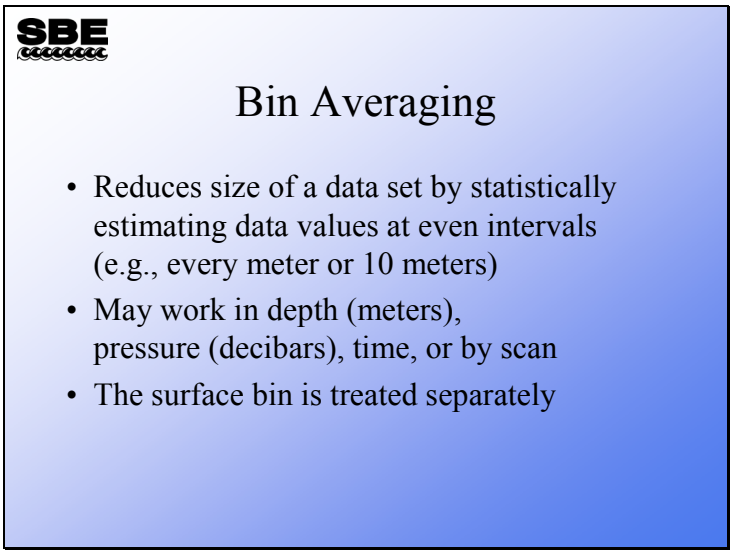
If you have time, repeat this for:

C:\Data\Module3\SBE19plus\Miami.con
C:\Data\Module3\SBE19plus\Miami.hex

Choose Pressure, Strain Gauge->db, Temperature -> ITS90 -> deg C, and Salinity

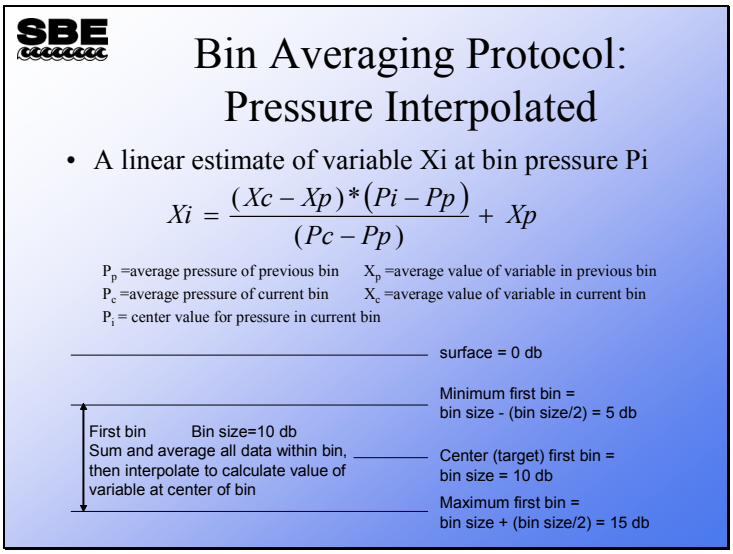
We thank the Hawaii Ocean Time Series program and the Rosenstiel School of Marine and Atmospheric Science for sharing this data with us.

Bin Averaging



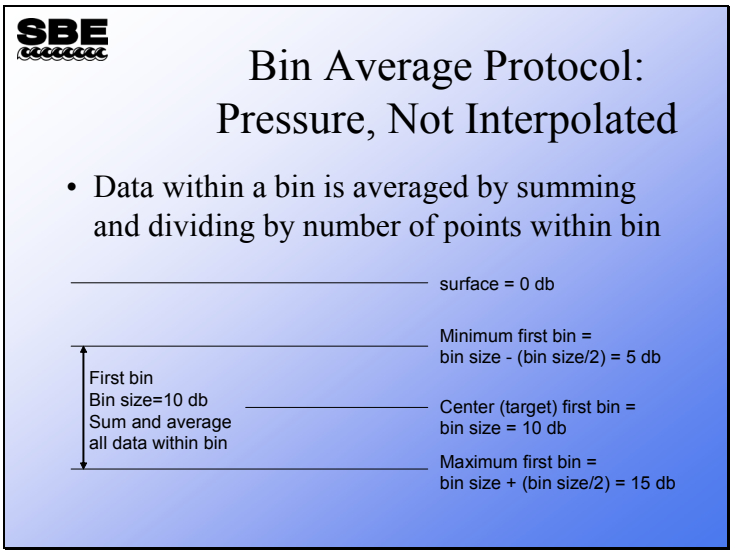
Bin averaging is a means of reducing your data set to a more tractable, and perhaps a more meaningful, size. The Bin Average module makes a statistical estimate of data values at a user-prescribed interval based on the surrounding data. You can bin data on the even meter or 10 meters. You can bin data with a bin size that represents the resolution of your instrument. For time series measurements, you can bin on time interval.

Bin Averaging: Processing Protocol



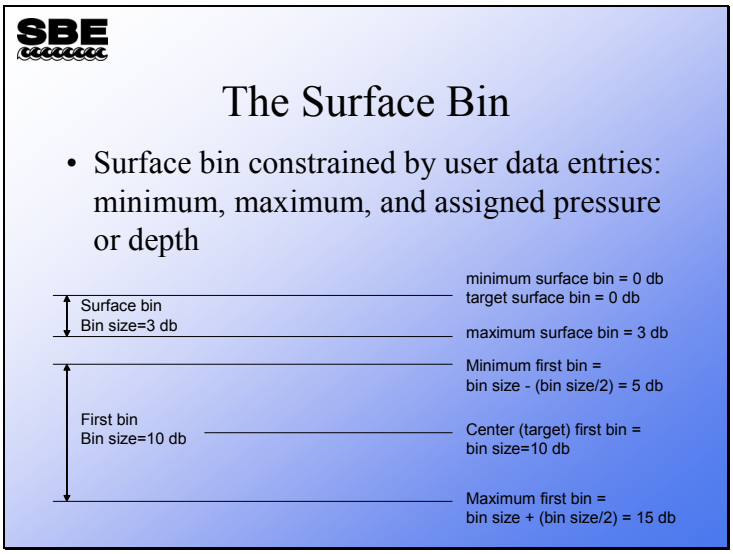
An estimate of each variable is made using the average value of that variable and pressure in the previous bin, and the average values of the variable and pressure in the current bin.

Bin Averaging*:* Processing Protocol



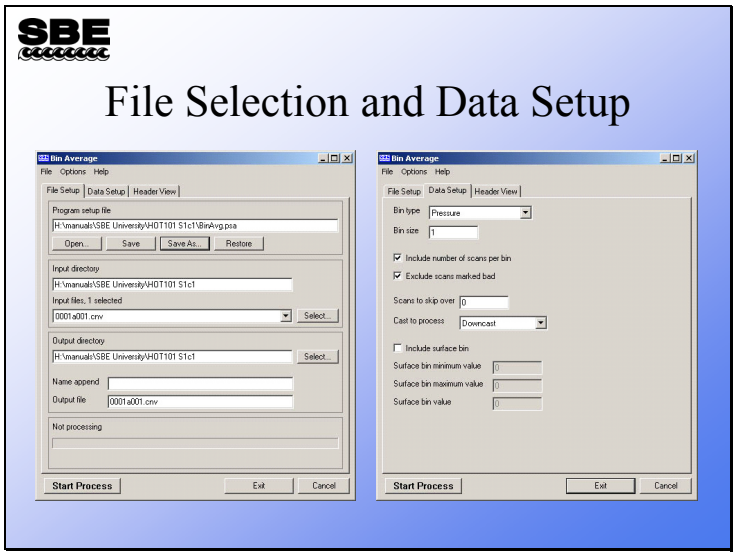
This protocol averages all the data within the bin, producing uneven bin pressures or depths. For example, if you are binning on 10-meter intervals, the first bin start is 5 meters and the end is 15 meters. All data within this window is averaged, producing a bin depth of approximately 10 meters (e.g., 10.123 meters).

Bin Averaging*:* Surface Bin



The surface bin is handled differently because the previous bin would be up in the air. The surface bin is assigned a beginning pressure or depth, an ending pressure or depth, and a target pressure or depth.

Bin Averaging: File Selection and Data Setup



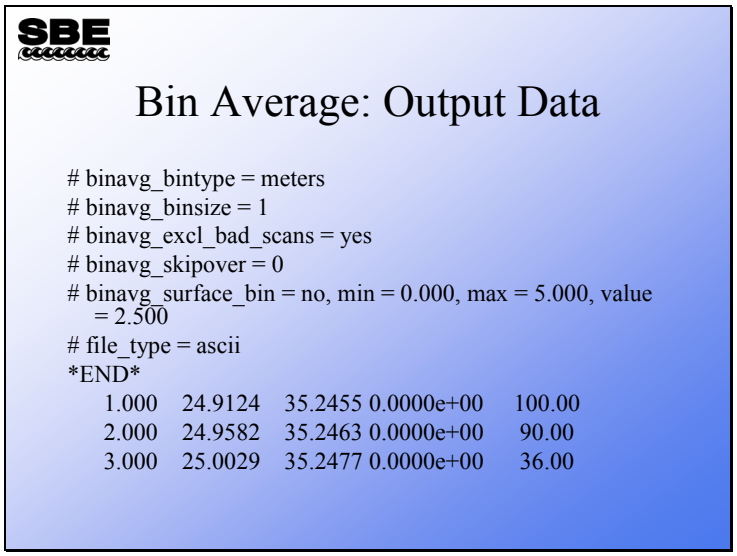
The Data Setup tab allows your choice of pressure, depth, time, or scan bins. You can include the number of scans per bin in the output file, which is useful for evaluating data from instruments with a low sample rate. Bins with 1 sample in them are not very accurate statistically.

You can skip data that you acquired while checking out your instrument before the cast started. Similar to previous processing, you can process the upcast, downcast, or both.

In the advanced data processing portion of the course, we will discuss techniques for removing suspect data. These data are marked in the data set as *bad scans*. When setting up *Bin Averaging*, you may exclude scans marked bad by previous processing steps.

As mentioned earlier, the surface bin is handled separately. Note that in our example the surface bin is not included, because we are binning on a 1-meter interval. If you bin on a small interval, it is very difficult to calculate a surface bin. For example, with 1-meter bins, a surface bin would run from 0 to 0.5 meters with value 0.25 meters; depending on the profiling and sampling speeds, there would be few samples within that depth. The surface bin is useful for a coarser bin size. For example, with 10-meter bins, the first bin starts at 5 meters and runs to 15 meters. You can succeed in calculating a surface bin that runs from 0 to 5 meters with value 2.5 meters.

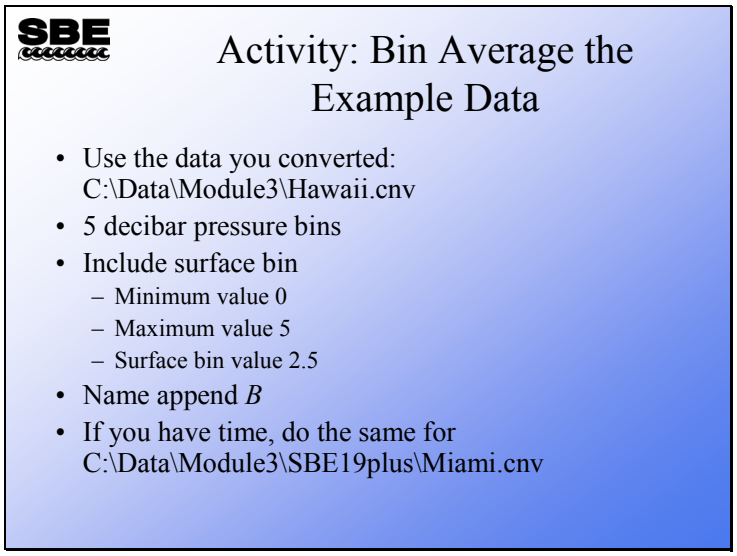
Bin Averaging: Output Data



The output columns for the example bin averaged data above are:

- Bin depth
- Temperature (°C)
- Salinity (PSU)
- Error flag
- Number of scans per bin

Activity



Click Start -> Programs -> Sea-Bird -> SBEDataProcessing-Win32

Click Run -> Bin Average

Click Select for Input files, and select C:\Data\Module3\Hawaii.cnv

Enter *Name append* of *B*

Output file should be Hawaii.cnv

Click the Data Setup tab:

Choose Pressure for *Bin Type*
Enter *Bin size* of 5
Check *Include number of scans per bin*
Check *Exclude scans marked bad*
Skip over 0 scans
Process the downcast

Click Start Process.

Open HawaiiB.cnv in Notepad or Wordpad and take a look at the header and data.

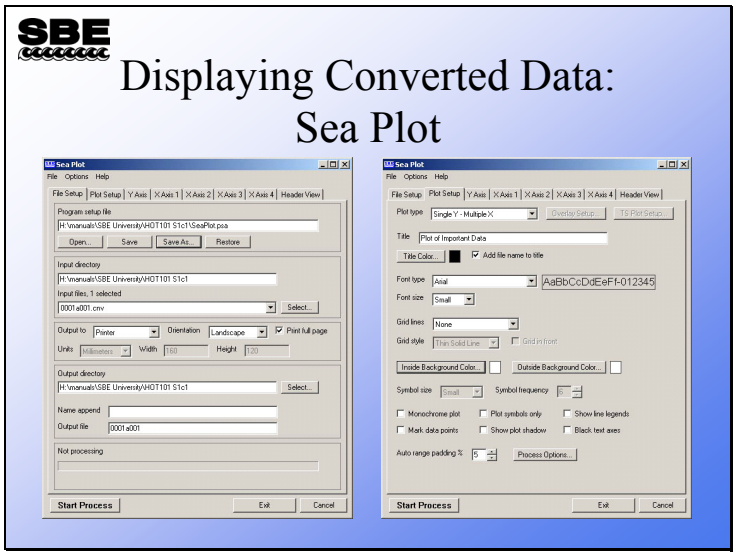
If you have time, repeat this for C:\Data\Module3\SBE19plus\Miami.cnv, using 1 decibar bins.

Sea Plot: Data Display

Sea Plot

- Sea Plot is an application that will plot converted data (*.cnv*)
- You may plot 1 – 4 parameters against a single Y axis
- You may plot 1 – 4 parameters against a single X axis (useful for time series data)
- You may select axis values interactively
- Sea Plot is part of the SBE Data Processing suite of applications

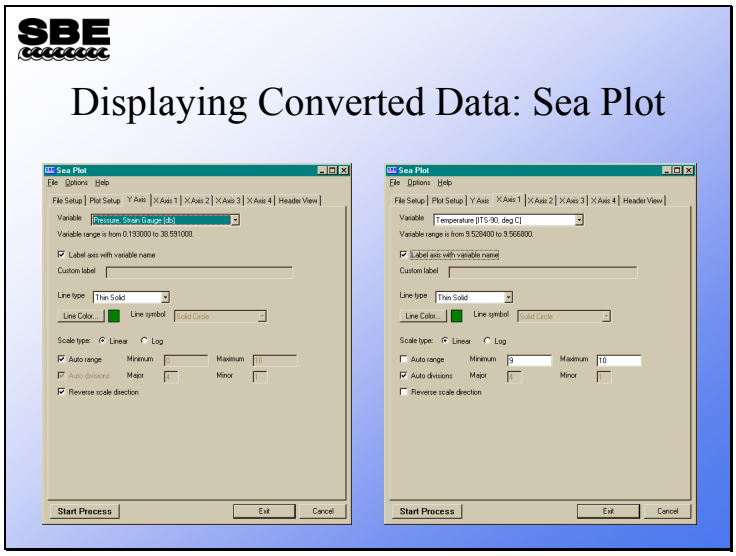
Sea Plot: Displaying Converted Data



The file setup dialog includes an entry for the program setup file or *.psa*. This allows you to store your plot setup for reuse. Output directory settings are included for batch processing.

Plot Setup allows you to choose the plot type (single Y, multiple X or single X, multiple Y), fonts, titles, and color schemes. Symbols are also specified here; if you are plotting to a black and white printer, symbols are very useful. The auto range padding entry sets the amount beyond the range of the data that the minimum and maximum axis values extend.

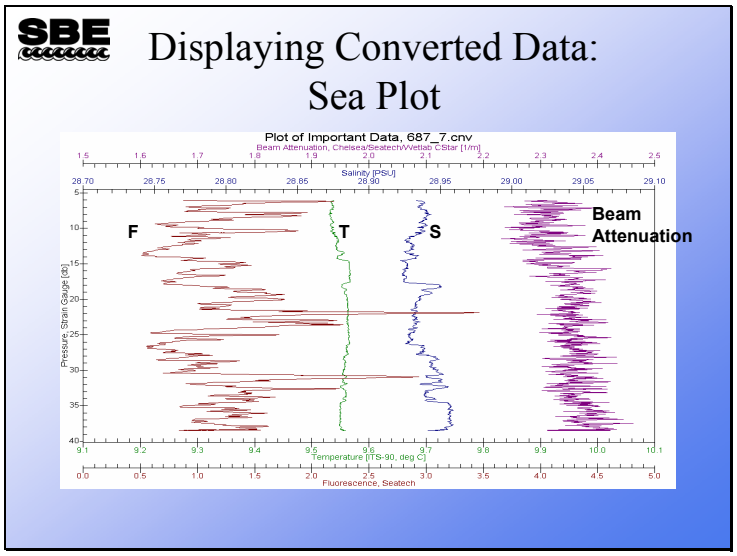
Sea Plot: X and Y-Axis Specification



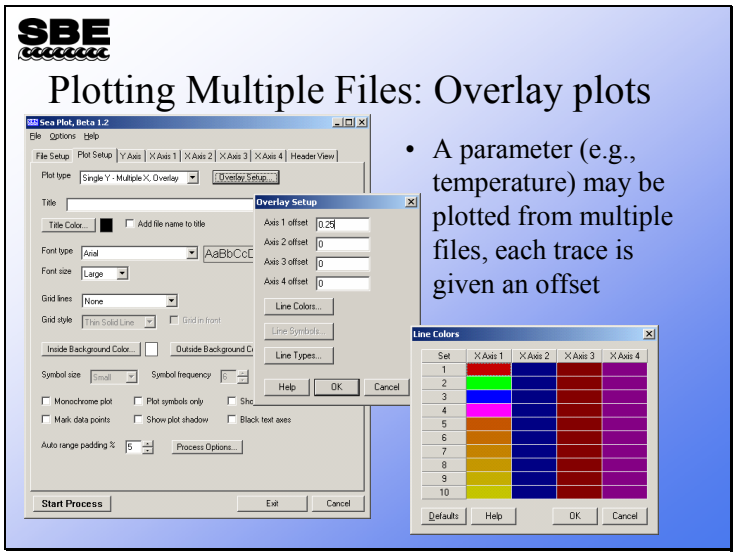
The axis setup tabs allow selection of variable, line type, and color. Plot range and scale direction are also specified here.

Note that the list of variables reflects the information in the selected .cnv file – only variables in the .cnv file are available for plotting, with the following exception. Sea Plot can calculate and plot salinity and/or density *on the fly*, if conductivity, temperature, and pressure data are in the .cnv file. This allows you to skip running the Derive module if you want a quick look at salinity and density before performing other processing steps.

Sea Plot: The Plot

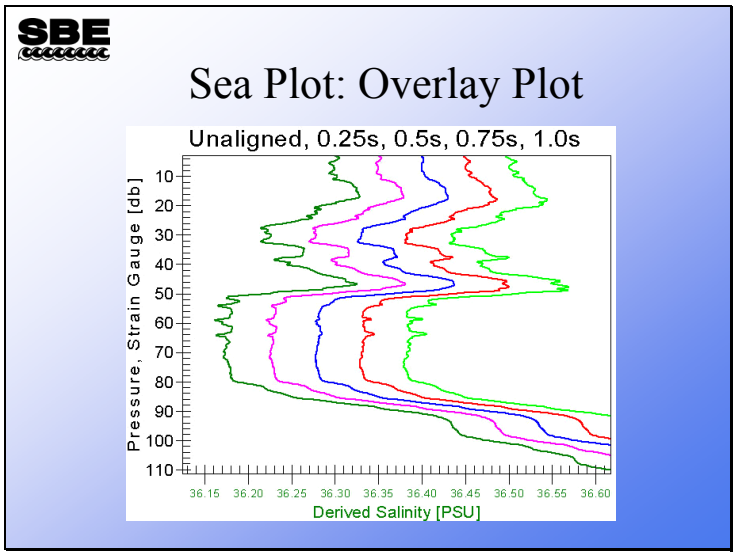


Sea Plot: Plotting Multiple Files, Overlay Plots

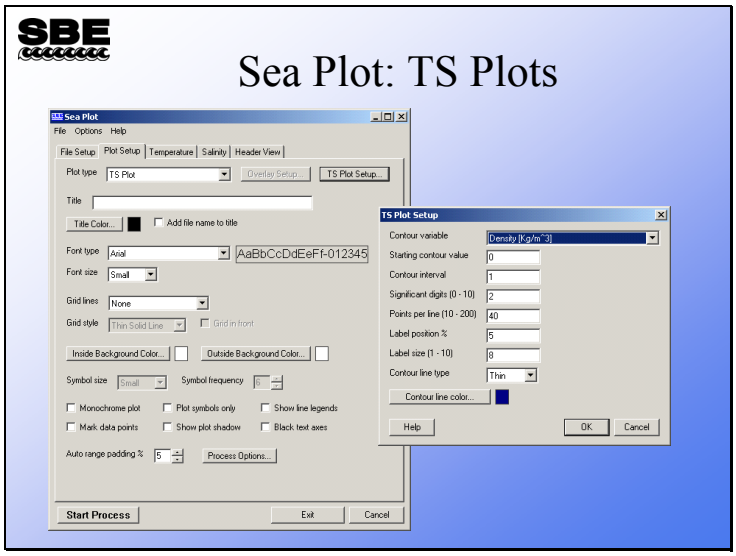


You can plot up to 4 parameters from multiple files by selecting the *overlay* plot type. To use this option you must specify the files in the order (left to right) you want them to appear. You must also enter an *offset* amount; this is amount of space between traces. For example, you might want to space temperature traces from casts taken at hour intervals at the same location by 0.2 degrees. You can also select the colors that each file will be plotted in. There is a color wheel that will allow selection of a graded set of line colors that is available by double clicking the axis identifier.

Sea Plot: Plotting Multiple Files

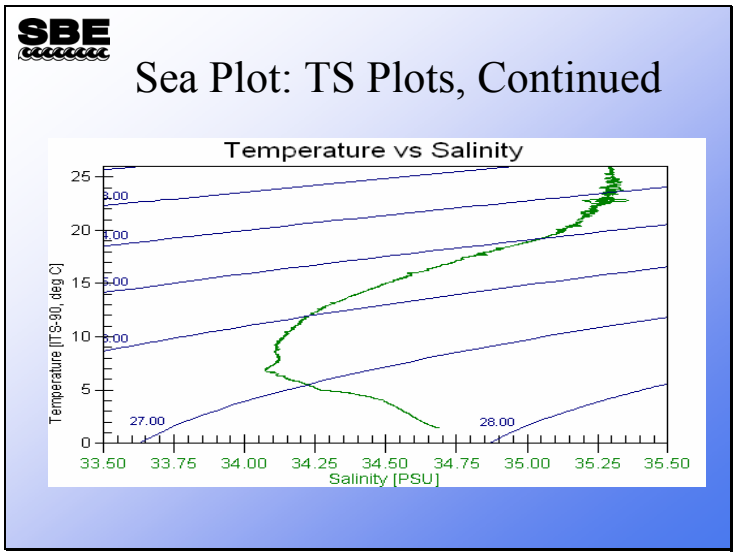


Sea Plot: TS Plots

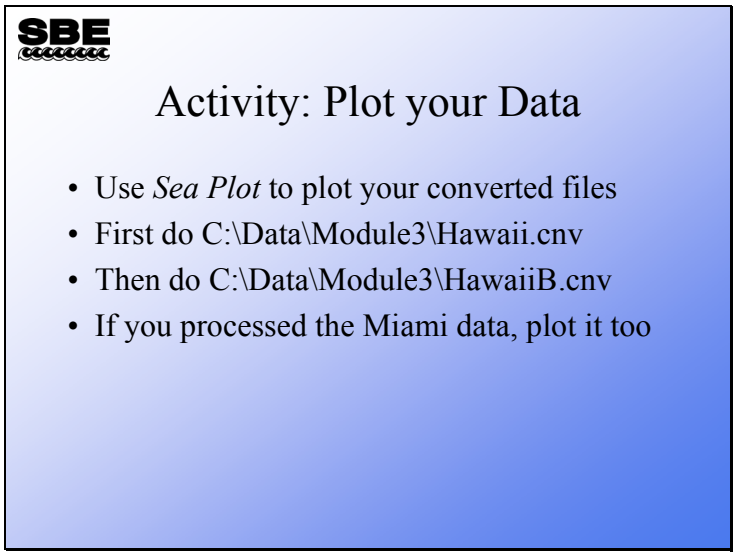


Temperature *versus* salinity plots are useful for discerning water masses. It is helpful if contours of constant density are placed on the plot as well. Sea Plot's TS plotting format allows you to do this. The file and axis menus above are as expected for Sea Plot. In addition you may define the density contours that are most useful for your application.

Sea Plot: TS Plots (*continued*)



Activity



Click Start -> Programs -> Sea-Bird -> SBEDataProcessing-Win32

Click Run -> Sea Plot

Click Select for Input files, and select C:\Data\Module3\Hawaii.cnv

Click the Plot Setup tab
Choose a *Plot type* of Single Y - Multiple X

Click the Y Axis tab
For *Variable*, choose Pressure, Digiquartz [db]
Check *Auto range*

Click the X Axis 1 tab
For *Variable*, choose Temperature
Uncheck *Auto range*
Enter a minimum of 0, a maximum of 30

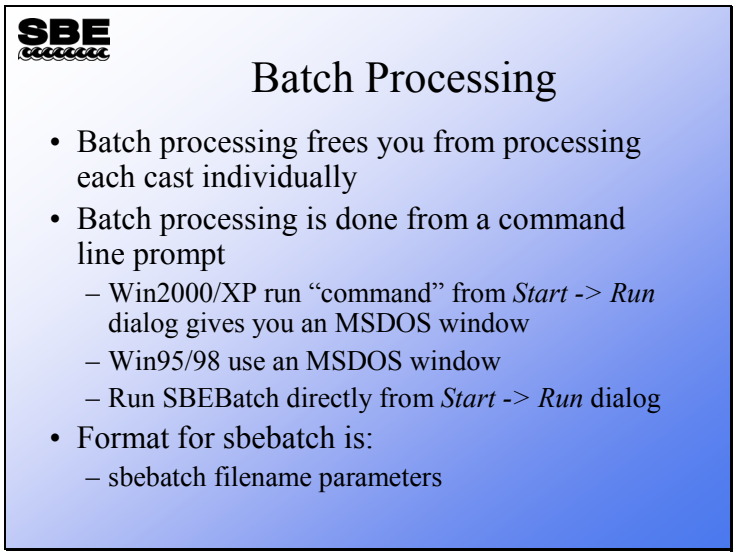
Click the X Axis 2 tab
Check *Include axis*
For *Variable*, choose Salinity
Uncheck *Auto range*
Enter a minimum of 34, a maximum of 36

Click Start Process

Repeat for C:\Data\Module3\HawaiiB.cnv

Repeat for Miami data

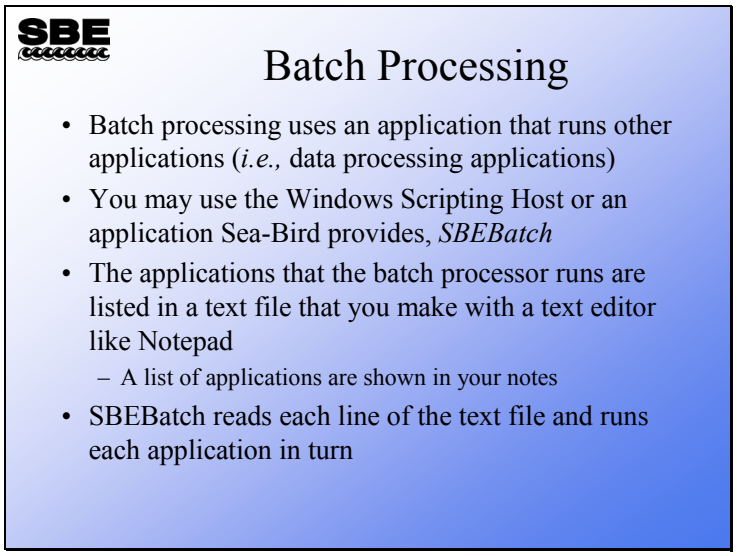
Data Processing of Large Numbers of Files



For processing large sets of cast data, batch mode processing automates the job. You can use the windows scripting host or a program provided with SBE Data Processing, SBEBatch.exe. Your batch file can take advantage of command line parameters and wild card characters.

You can run SBEBatch from a DOS window or from the Windows Run dialog (Start -> Run). In all the examples we'll use today (and the examples in the SBE Data Processing manual), we're assuming you are running from the Windows Run dialog box.

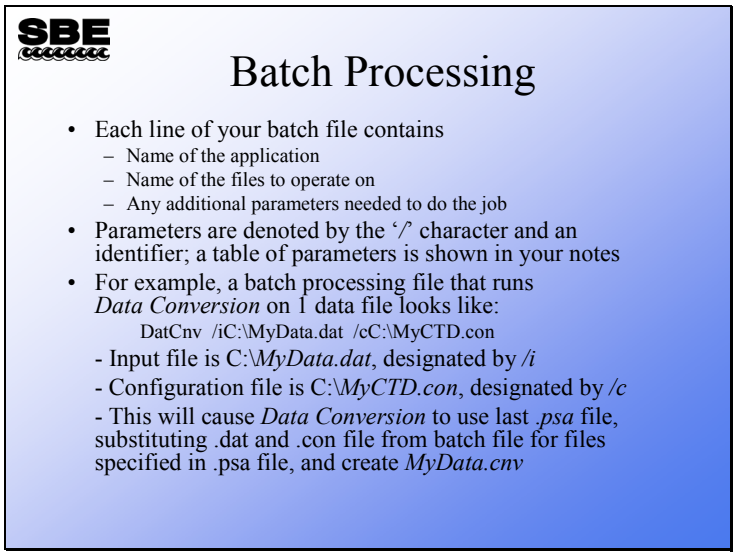
Data Processing of Large Numbers of Files (*continued*)



Applications:

Module	Process Name
Align CTD	Alignctd
ASCII In	Asciin
ASCII Out	Asciiout
Bin Average	Binavg
Bottle Summary	Bottlesum
Buoyancy	Buoyancy
Cell Thermal Mass	Celltm
Data Conversion	Datcnv
Derive	Derive
Filter	Filter
Loop Edit	Loopedit
Mark Scan	Markscan
Sea Plot	Seaplot
Section	Section
Split	Split
Strip	Strip
Translate	Trans
Wild Edit	Wildedit
Window Filter	Wfilter

Data Processing of Large Numbers of Files (*continued*)



A list of the most commonly used parameters follows; see the SBE Data Processing manual for a complete list:

Parameter	Description
/cString	Use *String* as instrument configuration (.con) file. *String* must include full path and file name. Note: If using /cString, must also specify input file name (using /iString).
/iString	Use *String* as input file name. *String* must include full path and file name. This parameter supports standard wildcard expansion: • ? matches any single character in specified position within file name or extension • * matches any set of characters starting at specified position within file name or extension and continuing until end of file name or extension or another specified character
/oString	Use *String* as output directory (not including file name).
/fString	Use *String* as output file name (not including directory).
/aString	Append *String* to output file name (before extension).
/pString	Use *String* as Program Setup (.psa) file. String must include full path and file name.
/xModule: String	Use *String* to define an additional parameter to pass to Module. Not all modules have x parameters; see module descriptions for details. If specifying multiple x parameters, enclose in double quotes and separate with a space. *Example*: Run Data Conversion, telling it to skip first 1000 scans: /xdatcnv:skip1000
#m	Minimize SBE Data Processing window while processing data, allowing you to do other work on computer.

If specifying multiple parameters, insert a space between each parameter in the list.

Data Processing of Large Numbers of Files (*continued*)

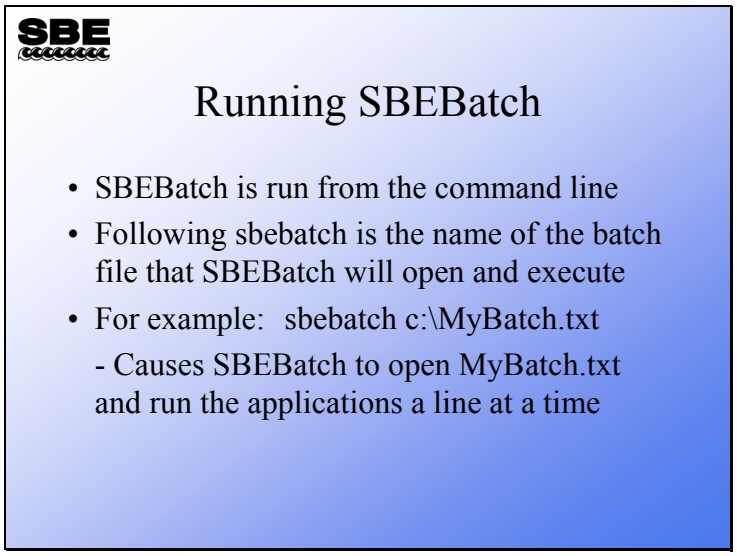
Batch Processing Script

- To process all the files in a folder use a wildcard: the '*' character
- For example, a batch processing file that runs Data Conversion on all data files in a folder looks like:

```
datcnv  /iC:\Data\*.dat  /cC:\Data\MyCTD.con
```

- Input files are all *.dat* files in C:\Data\
- Configuration file is C:\Data*MyCTD.con*

Data Processing of Large Numbers of Files (*continued*)



Here's an example of how to use batch processing to run Data Conversion and Derive to process all the files in C:\Data:

1. Run Data Conversion, entering the desired choices in the File Setup and Data Setup dialog boxes. Upon completing setup, press Save or Save As on the File Setup tab. The configuration is stored in the .psa file.
   Repeat for Derive.

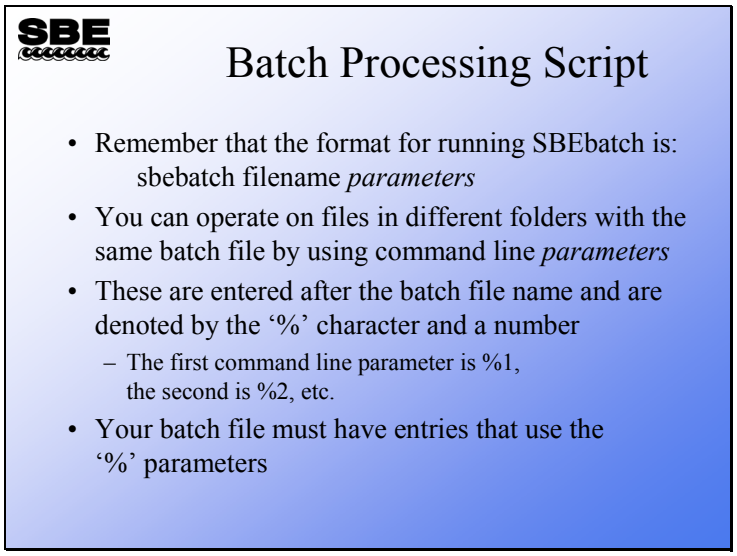
2. Create a batch file named batch.txt in C:\Data, which contains the following lines:
   @Lines starting with @ are comment lines, and have no effect on the result
   @Use these to document what you are doing in the batch file
   @Processing data from February 2006 Cruise
   datcnv /iC:\Data*.dat /cC:\Data\MyCTD.con
   derive /iC:\Data*.cnv /cC:\Data\MyCTD.con

3. Select Run in the Windows Start menu. The Run Dialog box appears.
   Type in the batch processing program name and the .txt file name:
   sbebatch c:\Data\batch.txt

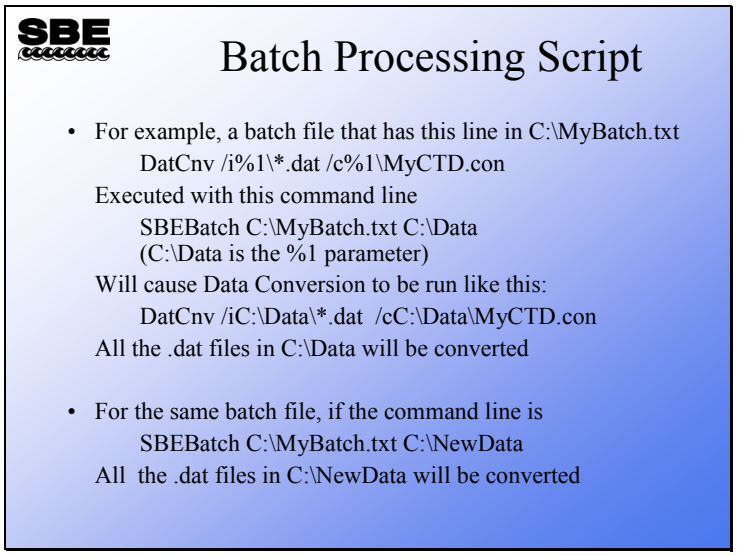
The results:

1. Data Conversion uses its last .psa file, substituting the .con file from the batch file for the .con file specified in the .psa file, and processes **all** .dat files in C:\Data, creating a .cnv file from each .dat file.
2. Derive uses its last .psa file, substituting the .con file from the batch file for the .con file specified in the .psa file, and processes **all** .cnv files in C:\Data (which were just created by Data Conversion), creating a .cnv file from each .cnv file.

Data Processing of Large Numbers of Files (*continued*)



Data Processing of Large Numbers of Files (*continued*)



Now let's add a bit more flexibility to the process. Here's an example of how to use batch processing to run Data Conversion and Derive to process all the data files in C:\Data\Leg1, C:\Data\Leg2, and C:\Data\Leg3:

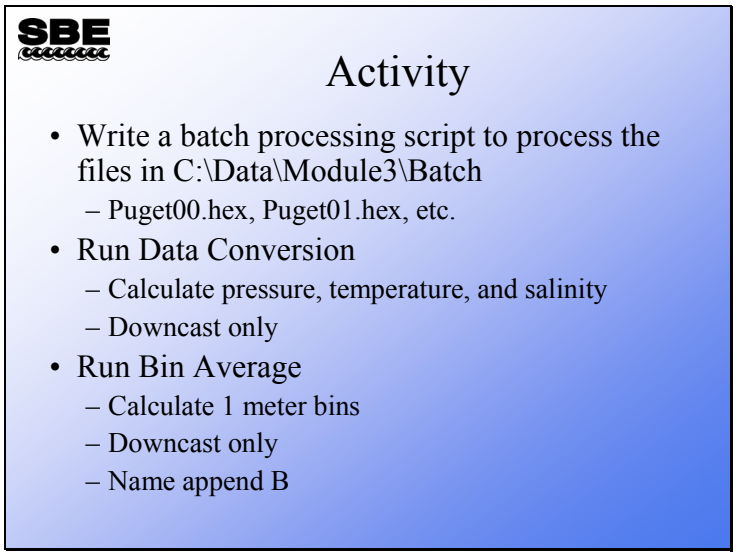
1. Run Data Conversion, entering the desired choices in the File Setup and Data Setup dialog boxes. Select *Match instrument configuration to input file* on the File Setup tab. Upon completing setup, press Save or Save As on the File Setup tab. The configuration is stored in the .psa file.
   Repeat for Derive.

2. Create a batch file named batch.txt in C:\Data, which contains the following lines:
   @Processing data from 3 legs of February 2006 Cruise
   datcnv /i%1*.dat
   derive /i%1*.cnv

3. Select Run in the Windows Start menu. The Run Dialog box appears.
   Type in the batch processing program name, the .txt file name, and the %1 parameter:
   sbebatch C:\Data\batch.txt C:\Data\Leg1
   Repeat for the files in Leg2 and Leg3:
   sbebatch C:\Data\batch.txt C:\Data\Leg2
   sbebatch C:\Data\batch.txt C:\Data\Leg3

The results:
1. Data Conversion uses its last .psa file, substituting the matching .con file for the .con file specified in the .psa file, and processes **all** .dat files in C:\Data\Leg1, creating a .cnv file from each .dat file.
2. Derive uses its last .psa file, substituting the matching .con file for the .con file specified in the .psa file, and processes **all** .cnv files in C:\Data\Leg1 (which were just created by Data Conversion), creating a .cnv file from each .cnv file.
3. Steps 1 and 2 are repeated for the files in C:\Data\Leg2 and C:\Data\Leg3.

Activity



1. Prepare Data Conversion and Bin Average to operate in batch mode:
   a. Process Puget00.hex with Data Conversion, using Puget.con
   b. Save the .psa file as C:\Data\Module3\Batch\DatCnv.psa
   c. Process Puget00.cnv with Bin Average
   d. Save the .psa file as C:\Data\Module3\Batch\BinAvg.psa
   e. Check to see that you were successful with Notepad
   f. Delete the .cnv files that resulted

2. Use Notepad to write your batch file, using a %1 parameter for the file locations

3. Save your batch file as C:\Data\Module3\Batch\MyBatch.txt

4. Launch a command line session: Click Start > Run.

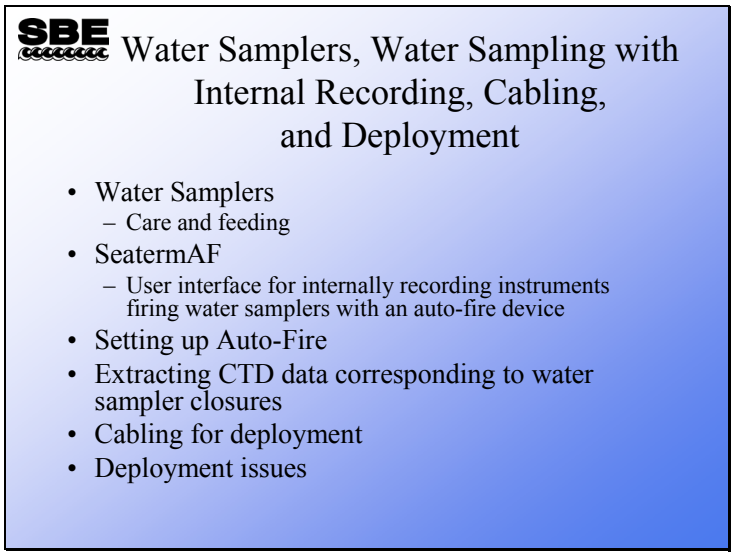
5. Run your batch file with the command line:
   Sbebatch C:\Data\Module3\Batch\MyBatch.txt C:\Data\Module3\Batch

6. Check to see that you were successful with Notepad

Module 4

Water Sampling and Deployment

Overview

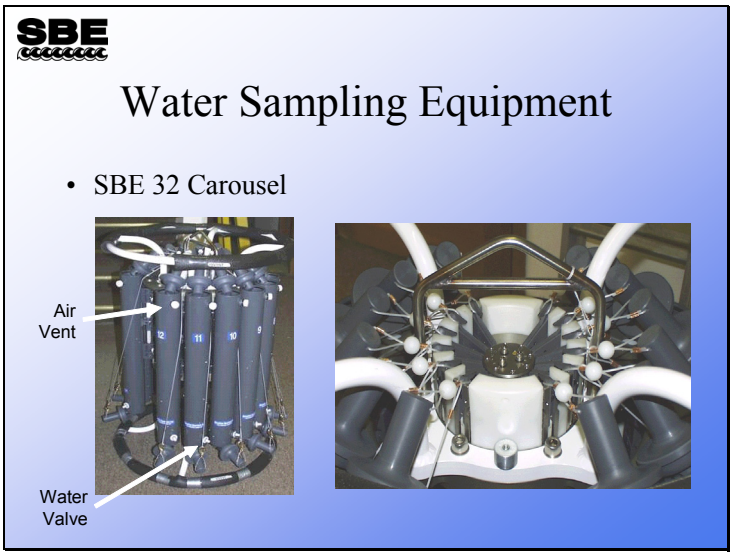


We are going to discuss the workings of water samplers and techniques for collecting water samples with internally recording instruments. SeatermAF, the user interface for water sampling with an auto-fire device, will be presented. We will also cover deployment issues, cabling, and preparation of the instrument package to go over the side of the ship.

When we finish this module you should be able to:

- Maintain your Carousel water sampler.
- Use SeatermAF to set up your auto-fire device.
- Create data summary tables that correspond to water samples.
- Cable your instrument from your computer room to the instrument on deck.
- Maintain your underwater connectors.
- Plumb your sensors properly.
- Prepare your instrument to make measurements in the ocean.

Water Sampling Components



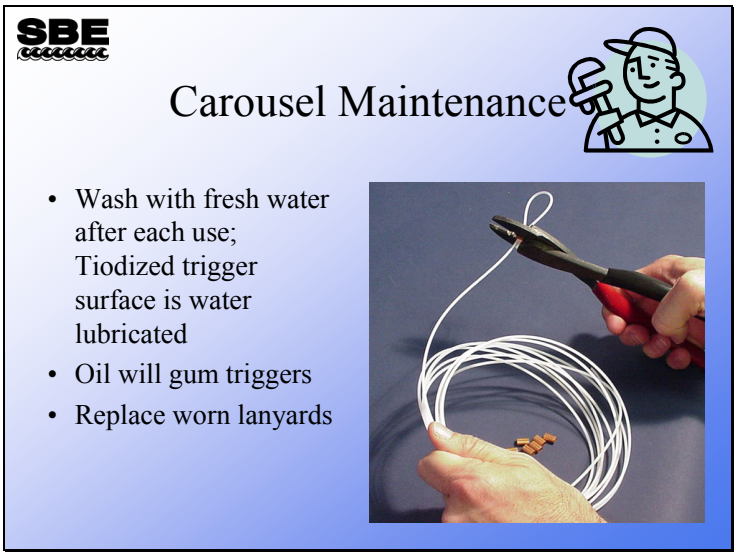
Here are pictures of water sampling equipment.

The water sampling package consists of:

- water sample bottles with their lanyards
- trigger mechanism
- upper and lower pylons that hold the bottle on the frame
- upper and lower frame that protects the package from collision with the side of the ship

The Carousel trigger mechanism is an electro-mechanical device. It operates by energizing a solenoid magnet that pulls a mechanical trigger, releasing the nylon lanyards that hold the top and bottom caps of the water sampler open.

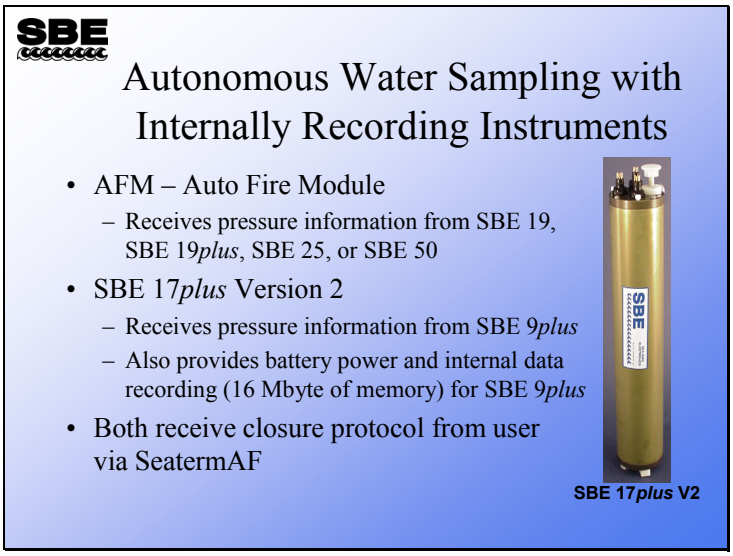
Carousel Maintenance



The trigger mechanism of the Carousel is made of titanium. The titanium pieces are coated with Tiodizing; this product is similar to anodizing aluminum. The Tiodized surface is water lubricating and should **never** be oiled with petroleum or silicon-based products. Rinse your trigger mechanism with fresh water after each cast and clean it periodically with soap and water.

Lanyards are made of nylon, 0.080-inch diameter, line-trimmer cord. They are crimped with copper nico-press sleeves. The line trimmer cord is available at most home and garden stores. The nico-press sleeves are available from Sea-Bird or most industrial supply stores.

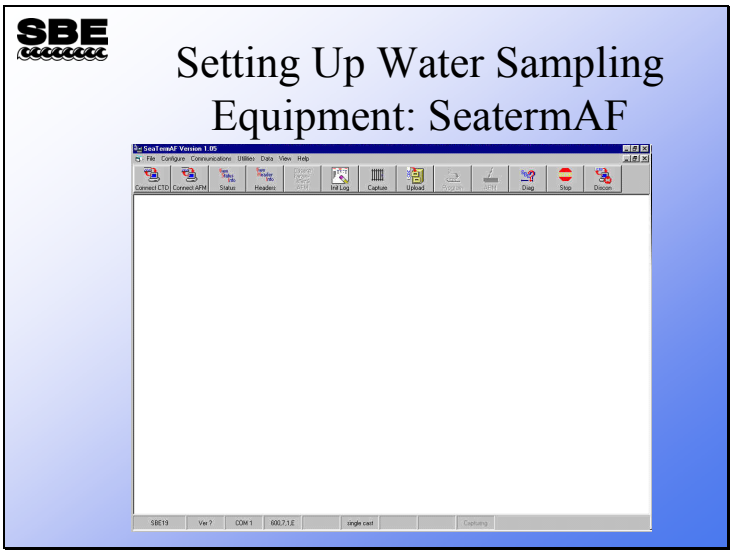
Autonomous Water Sampling with Internally Recording Instruments



Sea-Bird offers two products for closing water sampler bottles remotely. The AFM and the SBE 17*plus* V2 SEARAM both receive pressures from the CTD and are programmed to close bottles on operator-chosen criteria.

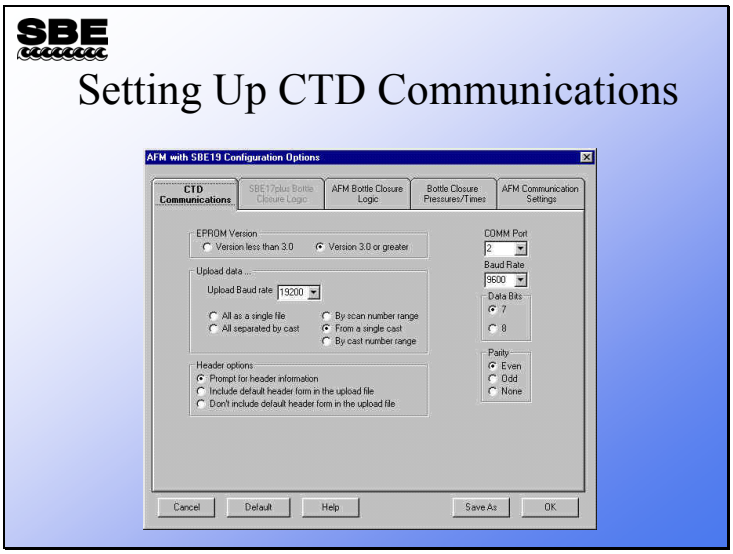
- The AFM is compatible with several CTDs, and closes bottles on downcast (descending), upcast (ascending), when the instrument package is stationary, or on elapsed time. For all options except elapsed time without CTD, the AFM must receive data from the CTD. If using the elapsed time option, you may record CTD data in the AFM each time a bottle is closed or you may use the AFM by itself, without a CTD.
- The SBE 17*plus* is much more straightforward to use, because there are fewer options. It only closes bottles on the upcast, and is only used with one type of CTD, the SBE 9*plus*.

Setting up Water Sampling Equipment with SeatermAF



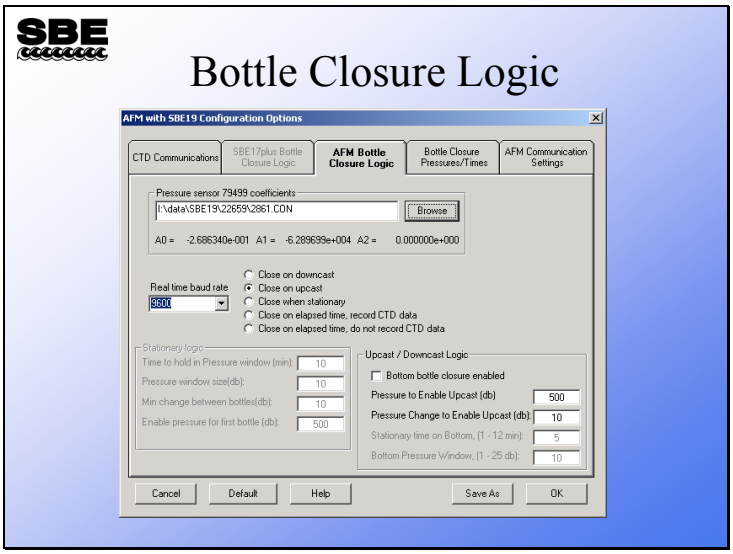
SeatermAF is a superset of Seaterm; it includes a simple interface for entering bottle closure parameters, and transfers that information to the auto-fire equipment. It is also used to set up the SBE 19, 19*plus*, 25, or 50 for operation, and to upload data from the auto-fire equipment (AFM or SBE 17*plus* V2).

SeatermAF: Setting Up CTD Communications



The CTD communications form allows you to select the communications parameters for your instrument as well as data transfer protocol and header options. As before, instruments with older firmware revisions are not able to change baud rate during data transfers. This form is an abbreviated version of the configuration form found in Seaterm.

SeatermAF: Setting up the Sampling Protocol

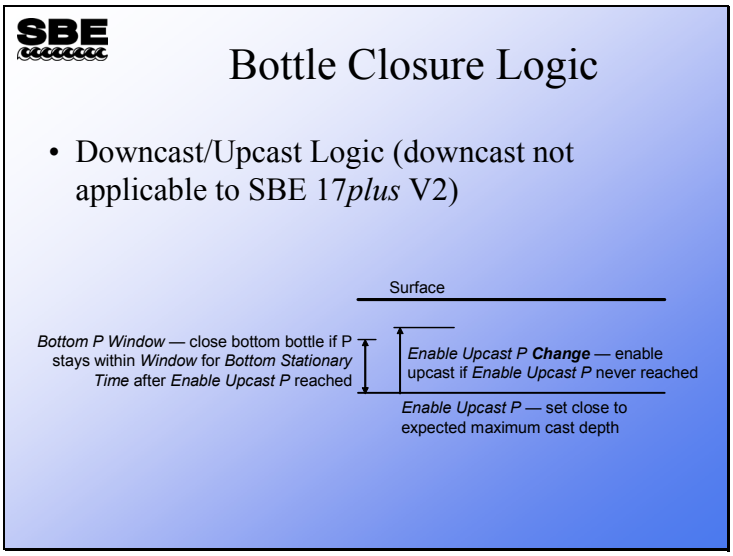


The bottle closure logic tab contains almost all the information that the AFM or SBE 17*plus* V2 need to close water sample bottles based on the closure protocol you select.

- With the AFM, you have the choice of closing bottles during downcast, during upcast, when the instrument package is stationary, or on time elapsed since the AFM was armed.

With the SBE 17*plus* V2, you can close bottles on the upcast only. The closure logic for the 17*plus* V2 follows.

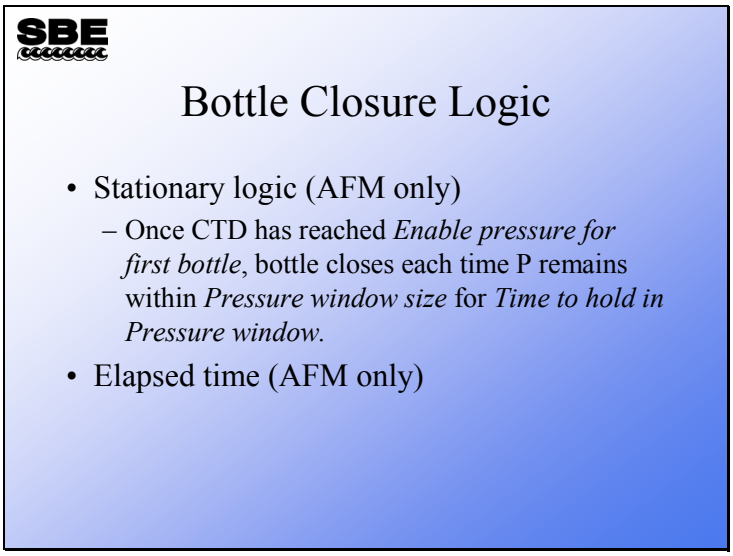
SeatermAF: Setting up the Sampling Protocol (*continued*)



The AFM and SBE 17*plus* V2 can both collect water samples during the upcast (as the instrument package is rising). Click *bottom bottle closure enabled* to take a sample at the deepest part of the cast. To collect a bottom bottle, you must specify a pressure to enable the bottom bottle, a length of time you will hold the instrument package stationary on the bottom, and the pressure window within which the instrument package will be considered stationary. In addition, you must specify *pressure change to enable upcast*. This parameter ensures that bottles are closed if the enabling pressure is not reached.

The AFM can also collect water samples during the downcast (as the instrument package is falling); parameters similar to those required for collecting on the upcast define the closure logic. Click *bottom bottle closure enabled* to take a sample at the deepest part of the cast. To collect a bottom bottle, you must specify a pressure to enable the bottom bottle, a length of time you will hold the instrument package stationary on the bottom, and the pressure window within which the instrument package will be considered stationary.

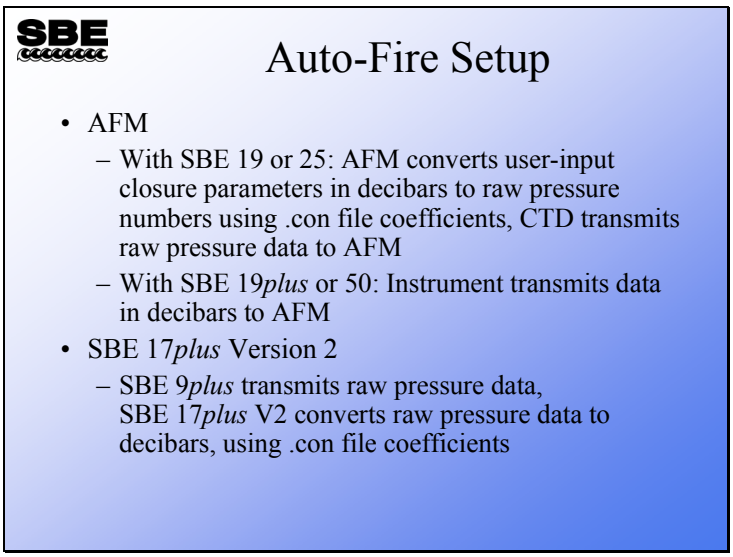
SeatermAF: Setting up the Sampling Protocol (*continued*)



With an AFM, samples can be collected when the instrument package is held stationary. The stationary logic dictates what constitutes stationary: how long to hold the package still and how large the pressure window is. You must set the pressure window size to allow for the rocking of the ship and set the time that you will hold the instrument in that window. You must also set an enable pressure; the package must go below this depth before the AFM will close any bottles. Also, you must specify the minimum pressure change between bottles to avoid multiple closures at essentially the same location.

With an AFM, samples can be collected on elapsed time. The AFM has an internal clock and closes water bottles on time from when it was given the Arm command.

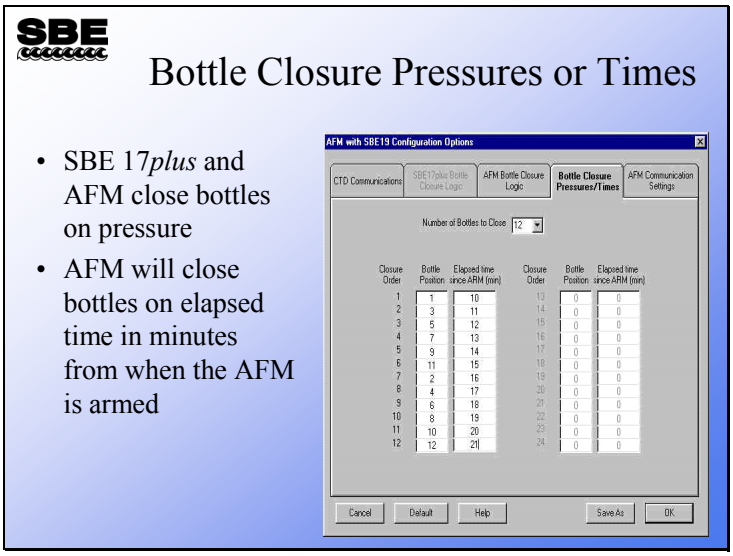
SeatermAF: Setting up the Sampling Protocol (*continued*)



You might remember that there was an entry for the configuration (.con) file on the Bottle Closure Logic tab.

- For the SBE 19 and SBE 25, the instrument configuration (.con) file (which includes pressure calibration coefficients) is required because the AFM receives raw data from the CTD. Rather than require the AFM to process the CTD pressure data, SeatermAF calculates what the raw pressure sensor output would be for the user-input closure pressures; these raw numbers are used by the AFM to determine when to close a bottle.
- The SBE 19*plus* and the SBE 50 send pressure in decibars to the AFM, so a configuration file is not required.
- For the SBE 9*plus*, the instrument configuration (.con) file (which includes pressure calibration coefficients) is required because the SBE 17*plus* V2 receives raw data from the CTD. The SBE 17*plus* V2 calculates pressures in decibars as data is received from the 9*plus*, and compares these pressures to the user-input closure pressures to determine when to close a bottle.

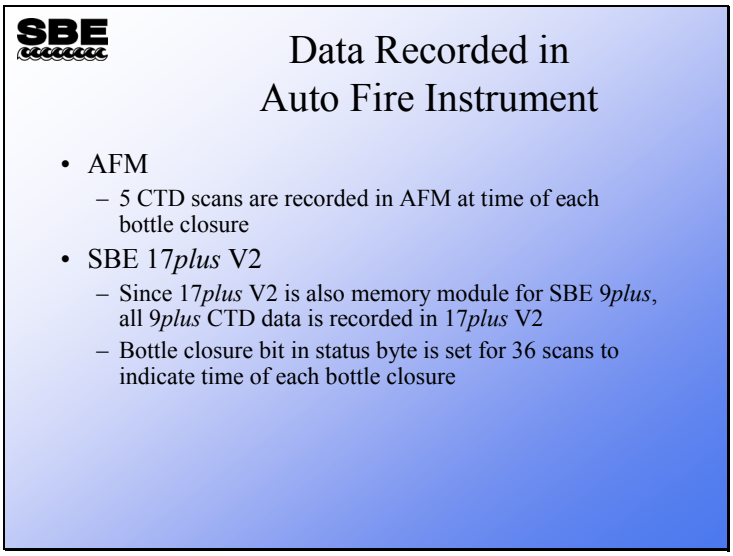
SeatermAF: Setting up the Sampling Protocol (*continued*)



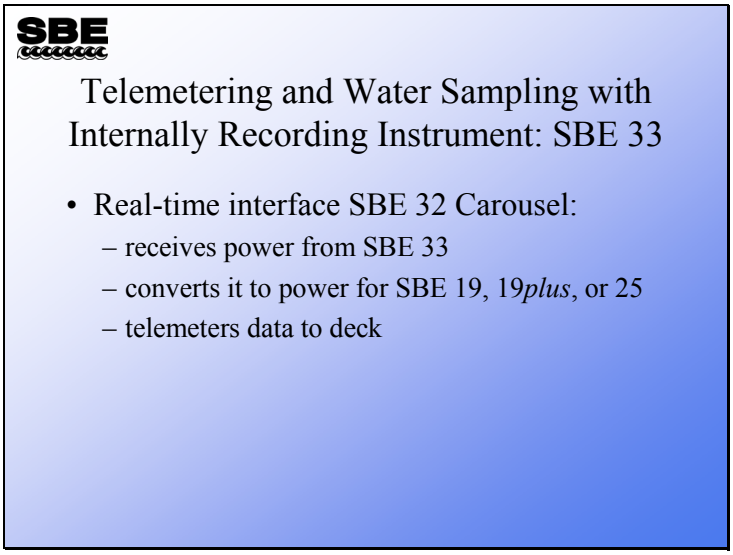
Once you have defined the governing bottle closure logic – on upcast, on downcast, when stationary, or on elapsed time – you need to enter the number of bottles to close and which bottle to close when. Bottles may be closed in any order desired.

- If closing on downcast, closure pressures must increase from closure 1 to the last closure (e.g., 10 db, 20 db, 50 db, etc.).
- If closing on upcast, closure pressures must decrease from closure 1 to the last closure (e.g., 500 db, 400 db, 350 db, etc.).
- If closing on elapsed time (time since AFM was armed), closure times must increase from closure 1 to the last closure (e.g., 2 minutes, 5 minutes, 10 minutes, etc.).

Data Recorded in Auto Fire Instrument



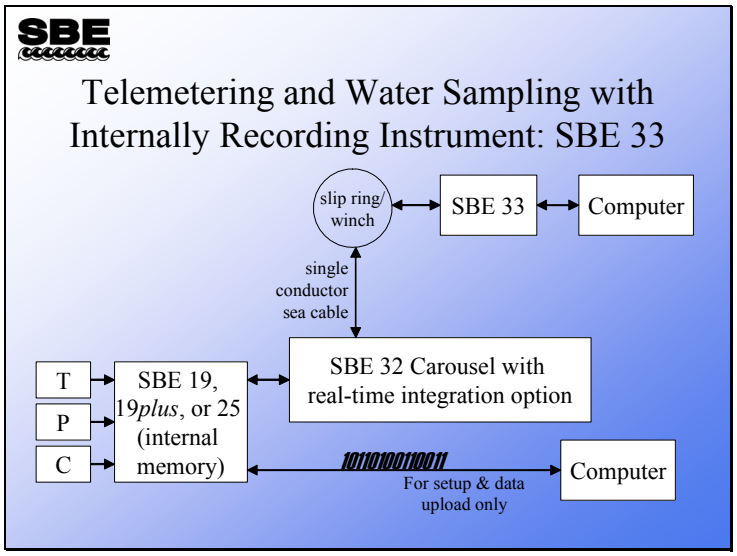
Real-Time Data and Water Samples from an Internally Recording Instrument



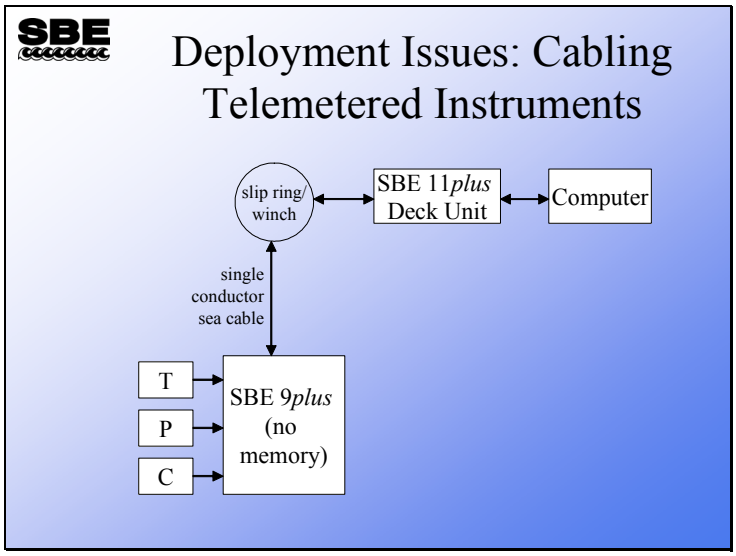
The SBE 33 provides power and telemetry for internally recording instruments.

Telemetry capability is over 10 km of sea cable.

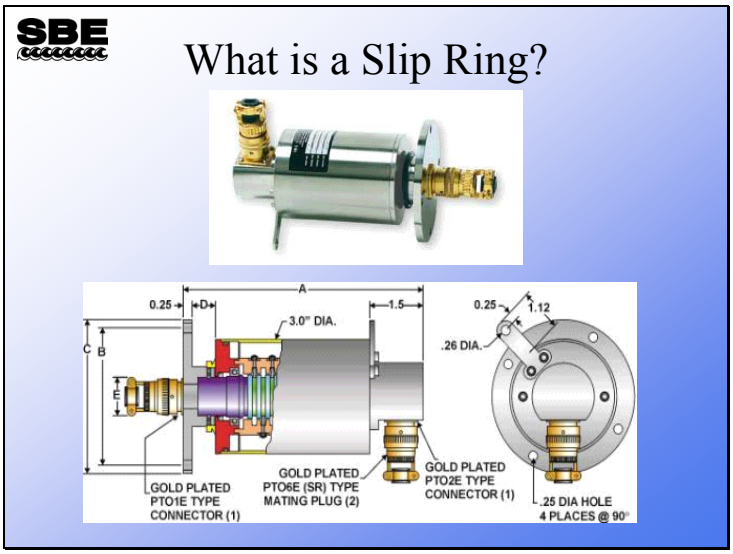
Cabling for the SBE 33



Deployment Issues



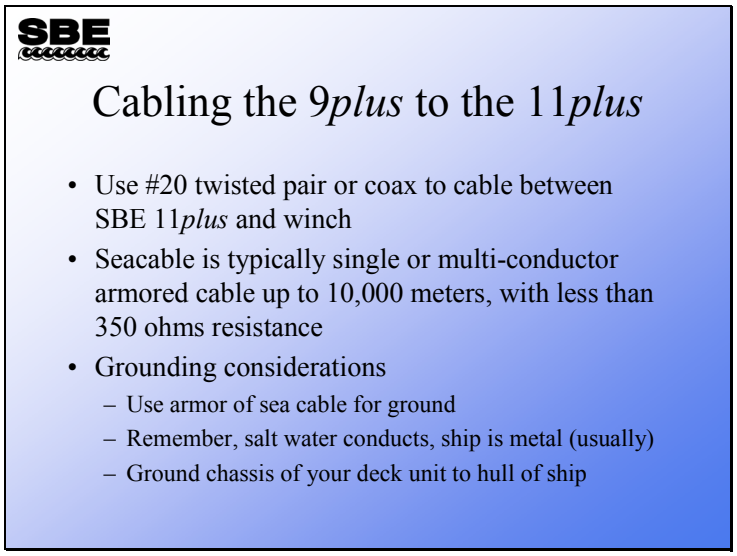
Deployment Components: Slip Rings



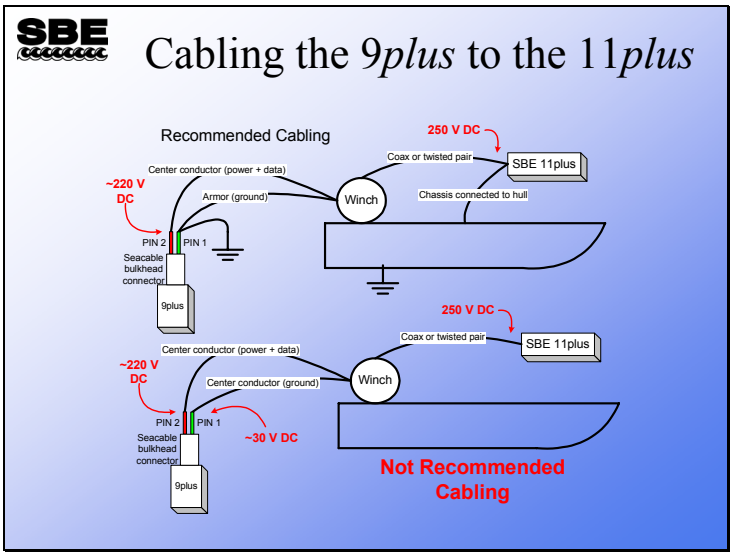
A slip ring is an electromechanical device that mounts to the part of the winch that rotates: the drum. When the instrument package is raised or lowered the drum turns, winding sea cable in or letting it out. The slip ring makes a connection between the sea cable rotating on the drum and the cable that connects to the SBE 11*plus* in the lab.

One side of the slip ring connects to the sea cable's internal conductor and the armor of the sea cable; this side has rings of metal separated by insulators arranged in a cylinder. The other side, which connects to the SBE 11*plus*, has conducting fingers that rest on the metal rings, providing continuity between the sea cable and the cable connecting to the 11*plus*.

Cabling the 9*plus* to the 11*plus*

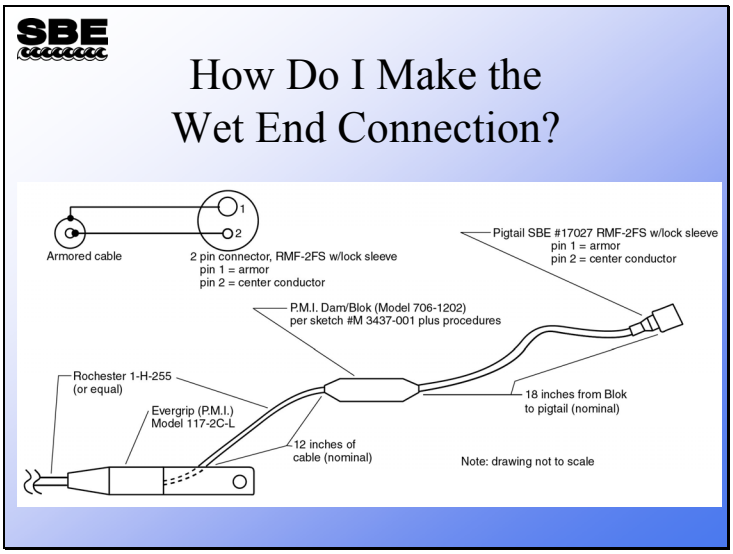


Cabling the 9*plus* to the 11*plus* (*continued*):

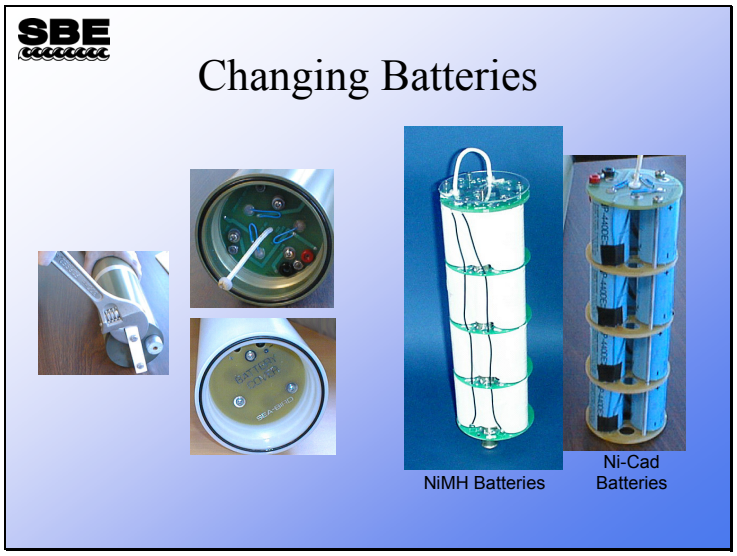


The slide above illustrates the recommended cabling for the SBE 9*plus* and the 11*plus* as well as a *not* recommended method. The primary difference between the two is that the recommended method utilizes the seacable armor as the return or ground for the SBE 9*plus*. This ensures that the underwater instrument package will be at the same potential, presumably ground, as the ship's hull. If the *not* recommended method is used, there is the possibility that the instrument package will be at a higher potential than the ship's hull and may cause injury to the crew that handles the over-the-side equipment.

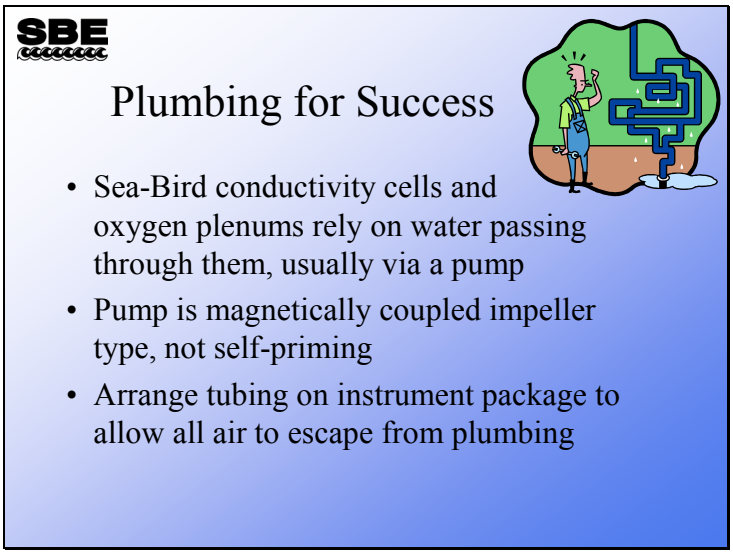
Deployment Components: Wet End Termination



Deployment Components: Batteries

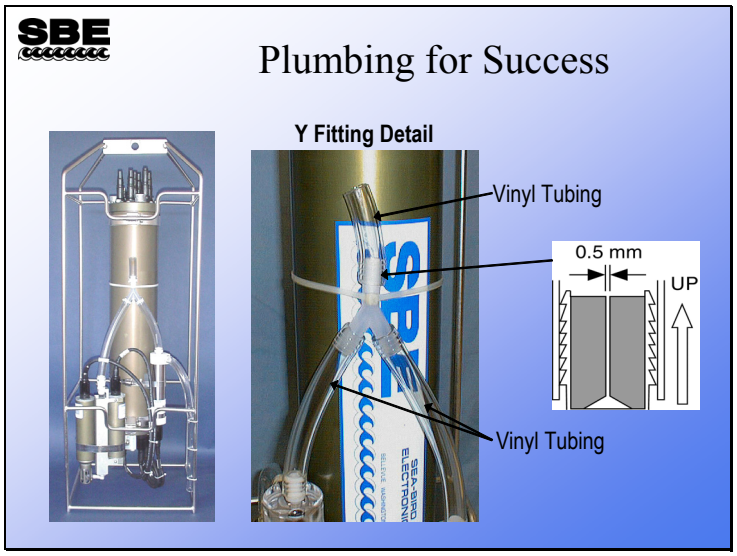


Deployment: Instrument Plumbing



Sea-Bird CTDs use a pump to maintain a constant flow of water through the conductivity cell and past the oxygen electrode. While this technique complicates the instrument package, it pays off in data quality. The tubing that connects the pump and the sensors must be arranged to allow all the air that is in the system while it is on deck to escape quickly when it is submerged. Failure to allow a path for the air to escape causes problems in the first 10 meters of data collection. Beyond 10 meters, the bubbles usually collapse sufficiently for the system to operate correctly. If bubbles collect in the pump, it will fail to prime. If bubbles are caught in the conductivity cell, the pump will fail to turn on. If bubbles are caught in the dissolved oxygen plenum, the dissolved oxygen signal will be in error.

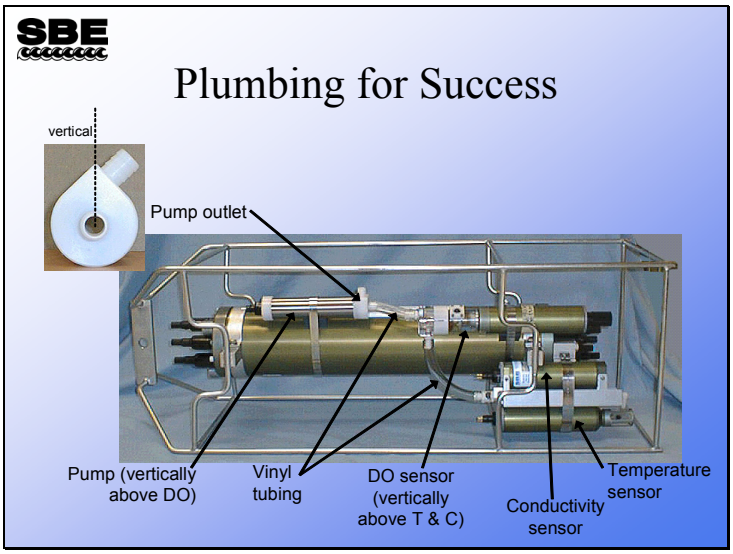
Deployment: Plumbing Examples



This slide shows the proper way to run the tubing for an instrument in a cage meant to be deployed vertically. Note the highest point in the plumbing is the top of the *Y*; there is a fitting with a small hole in the top of the *Y* that allows the air in the tubing to vent as the instrument goes into the water.

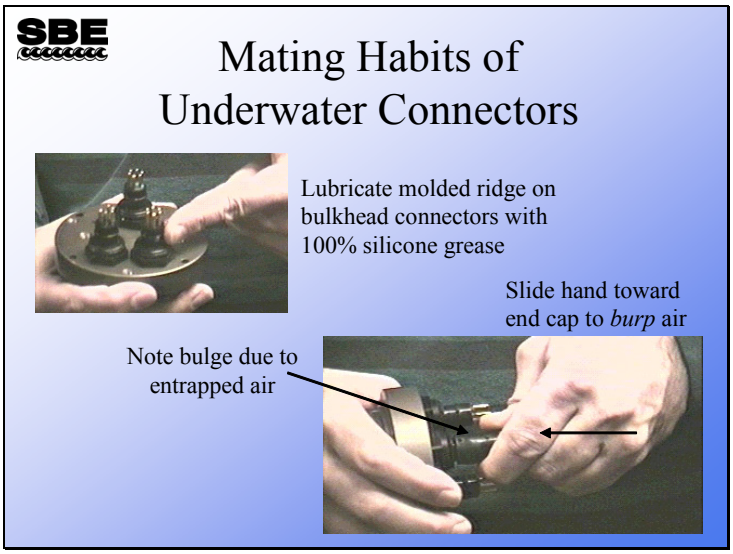
For the SBE 9*plus*, an exhaust tube runs from the pump outlet down the side of the cage, stopping at the same height as the T-C duct inlet. This equalizes pressure at the plumbing inlet and outlet, eliminating any acceleration / deceleration of water in the plumbing (which can cause small errors in the measurements). The exhaust tube is usually omitted for the SBE 19*plus* and SBE 25, due to the lower accuracy of those systems.

Deployment: Plumbing Examples (*continued*)



Instruments meant for horizontal deployment are easier to plumb. The pump is oriented so that the outlet is the highest point on the plumbing. Care must be taken to ensure there are no loops in the plumbing that would trap air. Because this system is meant to be deployed horizontally, there is no *sloshing* effect and no requirement for the SBE 9*plus* that the inlet and outlet be at the same height.

Deployment: Underwater Connections



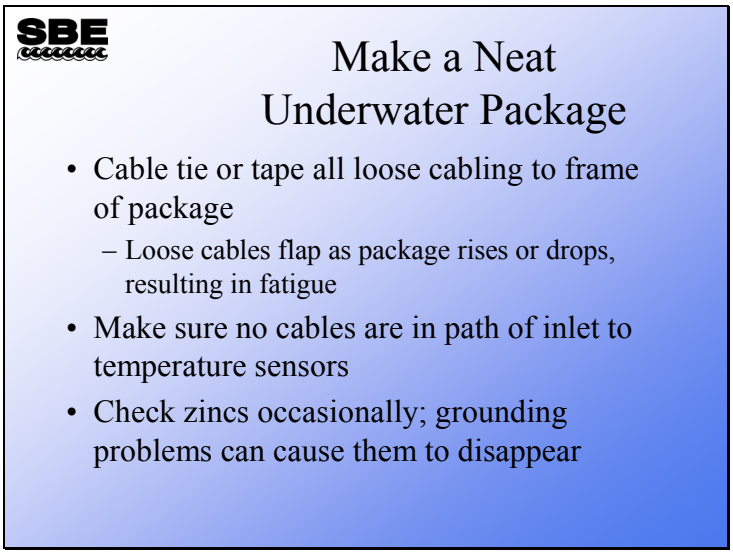
Underwater connectors require some care. The bulkhead connector is the part that is mounted on the end cap of the instrument. The bulkhead connector should be lubricated with a light coating of silicon grease; this acts as a lubricant and a sealant. When the cable is pressed onto the bulkhead connector, there is often air trapped inside between the bulkhead connector and the cable connector. If you slide your fingers down the body of the connector, you can force any trapped air out from between the two. This is described as *burping* the connector.

Avoid lubricants meant to break adhesions between bolts and nuts such as WD-40. This sort of lubricant can cause the seal between the rubber and metal parts of the underwater connectors to partially dissolve and part, resulting in the flooding of your instrument.

Deployment: Failed Underwater Connections

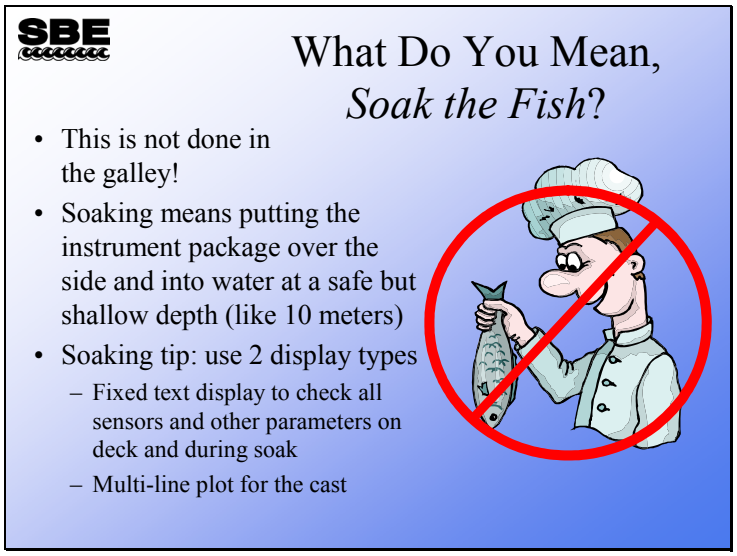
These connectors were not burped. As the instrument descended into the water, the air between the bulkhead and cable was compressed, allowing water to seep into the connection. Because there are numerous paths between power and ground present, the pins quickly corroded. You can observe this as a failed or noisy auxiliary sensor, or as main power dropping below that required to operate the instrument. In a pinch, you can try cleaning these up to continue using them, but they should be replaced as soon as possible.

Deployment: Be Neat!



Neatness counts! Secure all your loose cables. When you lower your instrument package at 1 meter per second, any loose cabling will flap. This sort of repetitive motion will fatigue the cables and shorten their working life.

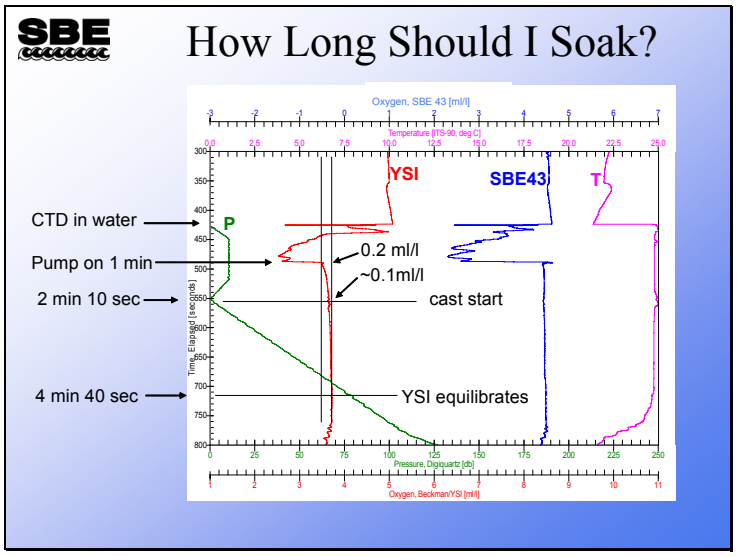
Deployment: Final Preparation



As you prepare to take a cast, it is considered good practice to place the instrument package in the water and allow it to equilibrate. This allows several good things to happen. The whole package comes to the surface temperature rather than the air temperature on deck, the conductivity cell wets with seawater, and the oxygen sensor comes to surface temperature (and in the case of older sensors, the oxygen sensor polarizes). Further, if you are working in real-time, you can quickly confirm the operation of the instrument and all the sensors. This is a great idea because nothing irritates the deck crew more than starting the cast only to bring the instrument package back aboard a few minutes later.

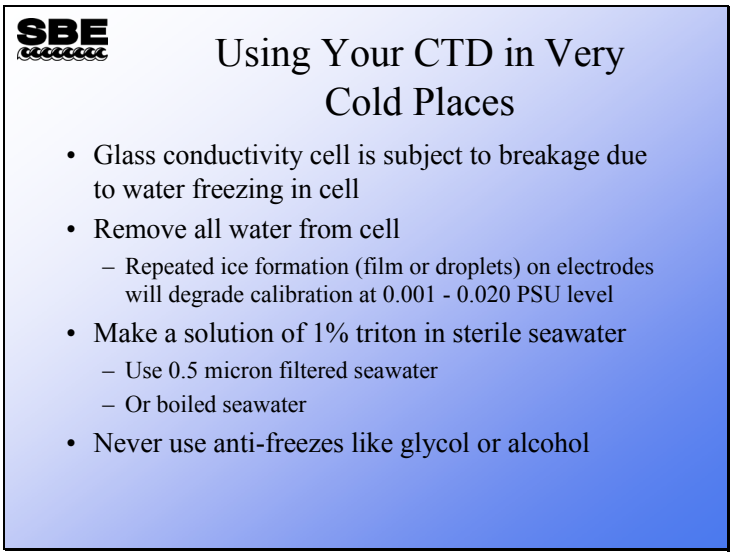
If you are using a real-time system, use 2 different display types in Seasave: a text display (fixed and/or scrolled) for deck and surface soak checkout, and a plot for the cast. The text display will tell you that the sensors are working and when the pump comes on.

Deployment: Final Preparation (*continued*)



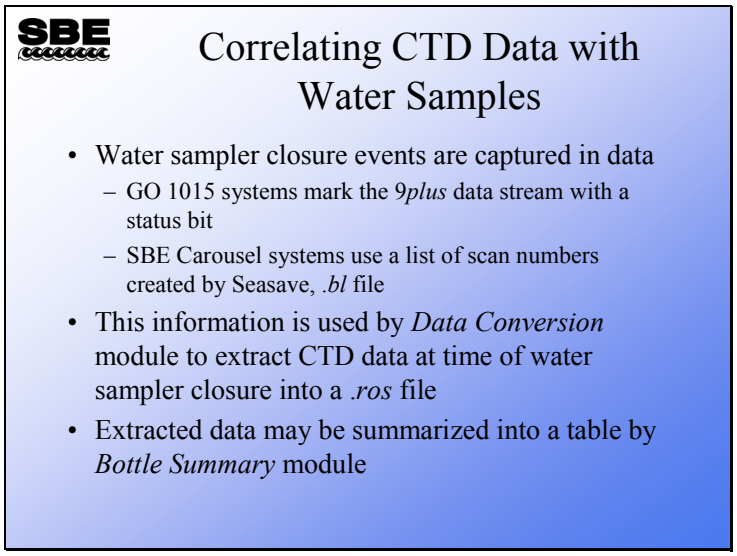
In this example the CTD was placed in the water and lowered to 10 meters for a brief soak. The YSI oxygen sensor began polarization and equilibration when the CTD was powered on. The plot clearly shows when the pump came on. At the time the cast started, the YSI was approximately 0.1 ml/l from the surface oxygen value. This represents about a 3% error. The YSI was fully equilibrated at about 4 minutes 40 seconds, or 65 meters into the cast. The SBE 43 is much faster to equilibrate and is ready as soon as the air leaves the system and the pump comes on.

Deployment: Final Preparation (*continued*)



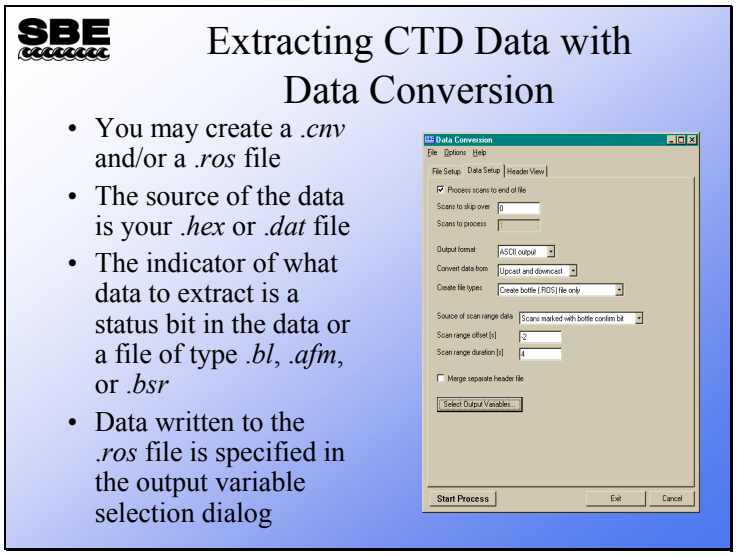
Commercially available alcohol or glycol antifreezes contain trace amounts of oils that will coat the conductivity cell and the electrodes.

Correlating CTD Data with Water Samples



Water samples are typically used in analyses that cannot be preformed *in-situ*, usually of a chemical or biological nature. These analyses are much more useful when they can be combined with CTD measurements made at the time of the water sample. There are two steps to providing a table of CTD data that corresponds to water samples. The *Data Conversion* module creates a *.ros* file that contains CTD data scans from the data logged at the time the water sample was collected. The *Bottle Summary* module creates averages and standard deviations from this data, rendering the data into a format that can be easily used by spreadsheets or other applications.

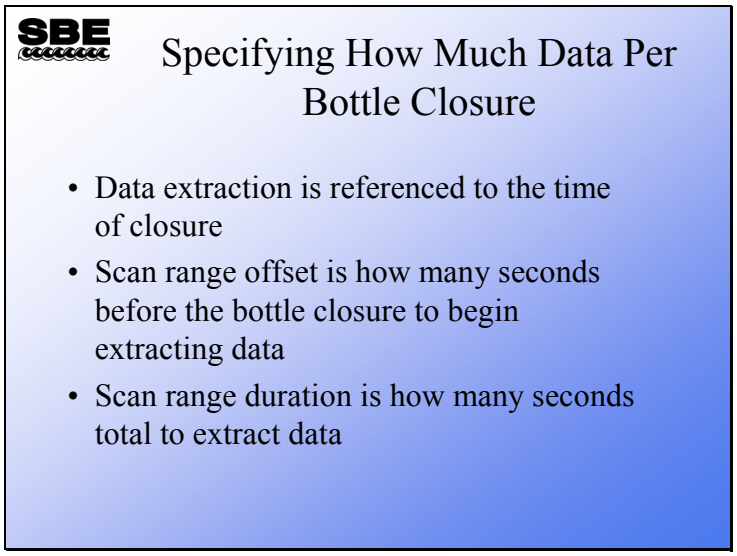
Extracting CTD Data for Water Samples with Data Conversion



The Data Conversion module creates a .ros file containing the same variables that the .cnv file contains, with scans logged around the moment a water sample was collected. Data Conversion determines when the water sample was taken by either a status bit in the SBE 9*plus* data stream when a G.O. 1015 is used to collect samples, or by a .bl or a .bsr file that is created by Seasave when the instrument package is equipped with an SBE 32 Carousel.

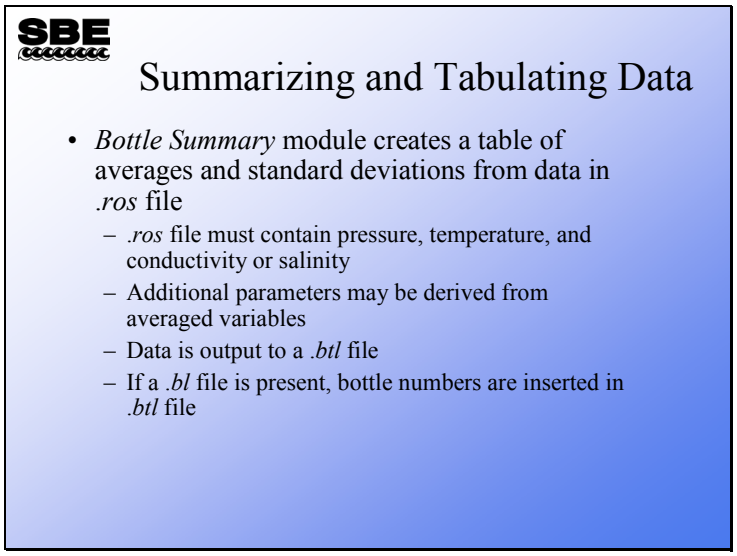
For instrument packages using the AFM, a file of data stored by the AFM (.afm) is the source of the scan markers.

Extracting CTD Data for Water Samples with Data Conversion (*continued*)



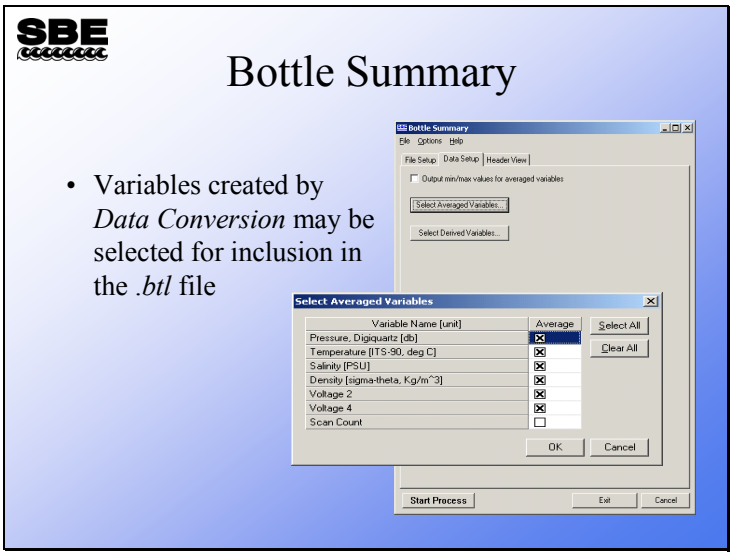
The range of data to copy out of the .cnv file into the .ros file is specified in seconds. You may copy a maximum of 1440 scans per bottle closure. For an SBE 9*plus* system operating at 24 Hz, 4 seconds of data is 96 scans. For an SBE 19 operating at 2 Hz, 4 seconds of data is only 8 scans.

Bottle Summary: Summarizing Water Sample Data

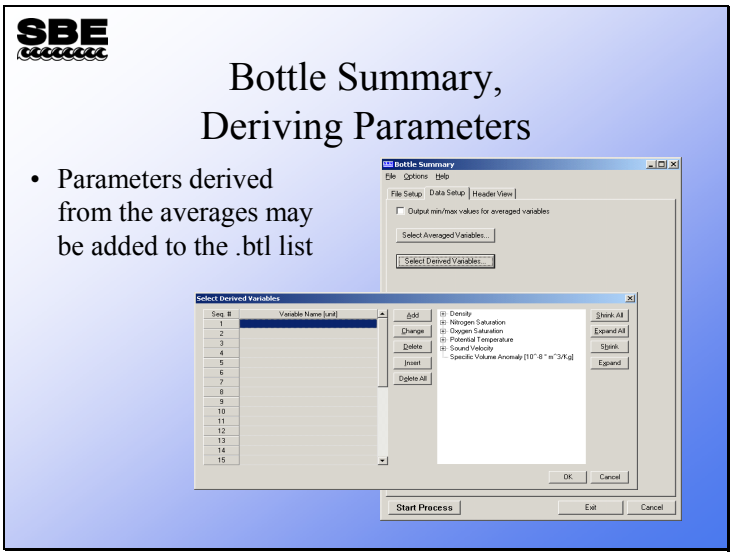


The *.ros* file created by *Data Conversion* contains a set of data scans for each water sample taken. The *Bottle Summary* module takes the process one step further by averaging the scans for each water sample into a single line of data that contains averages and standard deviations for each of the parameters in the *.ros* file. In addition, you may add derived parameters to this list. The derived parameters are calculated from the averages of the data contained in the *.ros* file.

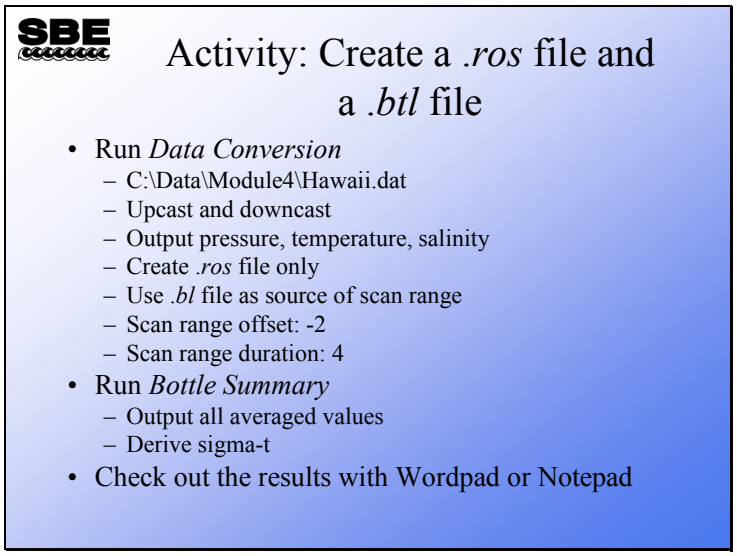
Bottle Summary: Summarizing Water Sample Data (*continued*)



Bottle Summary: Summarizing Water Sample Data (*continued*)



Activity



Because you are already familiar with *Data Conversion*, we will not list step-by-step instructions for this part of the activity.

After you have run Data Conversion, run *Bottle Summary* (number 8 on the data processing menu)

Select an instrument configuration file, C:\Data\Module4\Hawaii.con

Select a data file, C:\Data\Module4\Hawaii.ros

Click the Data Setup tab

Click the Select Averaged Variables button

Click the Select All button

Click OK

Click the Select Derived Variables button

Click the first Variable name entry

Click Density -> sigma-t

Click the Add button

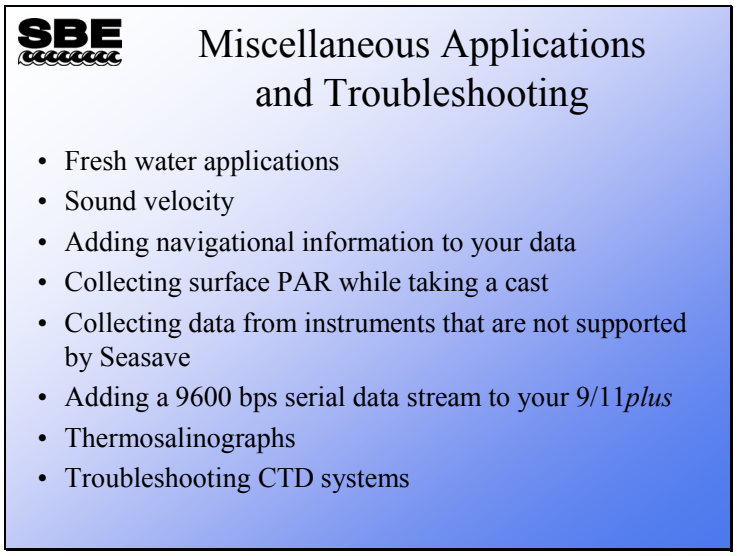
Click OK

Click Start Process

Module 5

Miscellaneous Applications and Troubleshooting

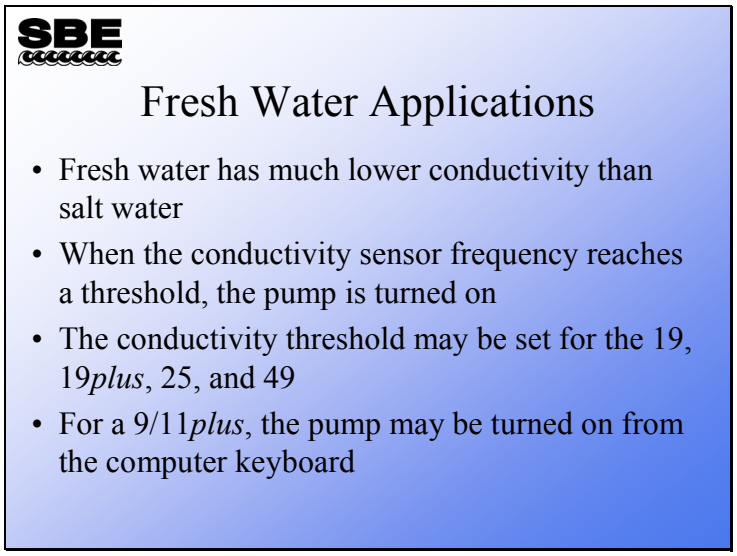
Overview



In this module we will discuss somewhat less common applications and troubleshooting. By the end of this module you should be able to:

- Operate your CTD in fresh water.
- Speak knowledgeably about techniques of measuring sound velocity.
- Add navigational information to your CTD data.
- Collect surface PAR data with your cast.
- Display data collected from instruments not supported in Seasave in a meaningful way.
- Know what options to have installed if you need to add a serial instrument to your instrument package.
- Set up and operate an SBE 21 or SBE 45 thermosalingraph,
- Do some basic troubleshooting.

Fresh Water Applications

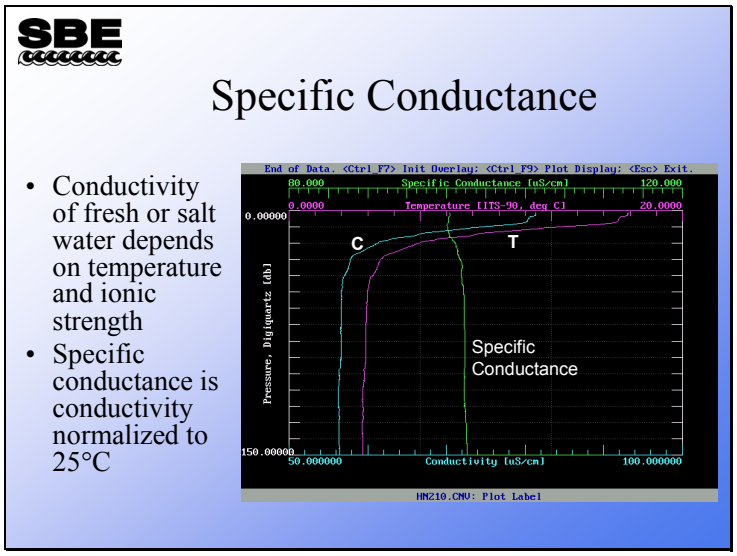


Using a CTD in fresh water requires some modification of the instrument setup for internally recording instruments or of hardware for the 9*plus*. The issue is the pump turn-on signal. As delivered, Sea-Bird instruments are configured for use in saltwater. They sense the rising conductivity frequency associated with immersion in saltwater, and turn on the pump after a short delay that allows the air in the plumbing to escape.

In internally recorded instruments and the SBE 49, the user can set the pump turn-on threshold frequency. For fresh water, this should be set to 5 Hz above the frequency seen at zero conductivity (wet cell rinsed with deionized water). However, values closer to the zero frequency may be required; check your data carefully to make sure the pump is turning on properly.

SBE 9*plus* CTDs may have optional hardware that allows the operator to turn on the pump from the computer keyboard.

Specific Conductance



The conductivity of fresh or salt water is strongly dependent on temperature. Specific conductance is used to visualize the conductivity without the temperature dependence. The equation shown below has the effect of normalizing the conductivity to 25° C.

$$\text{Specific Conductance}\left(\mu mhos/cm\right) = \frac{\left(C \times 10{,}000\right)}{\left(1 + A \times \left(T - 25\right)\right)}$$

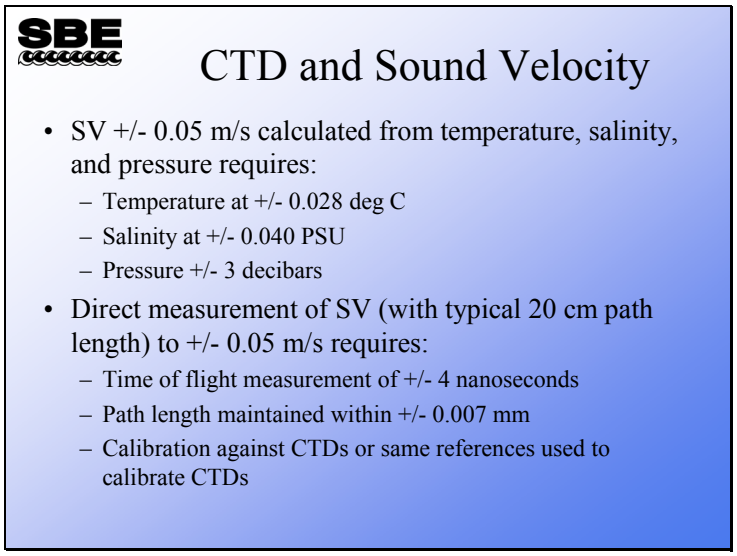
where:

A = 0.019 to 0.020 = thermal coefficient of conductivity for natural salt ion solutions (Seasoft uses this formula with A = 0.020)

C = conductivity [S/m]

T = temperature [°C]

Sound Velocity



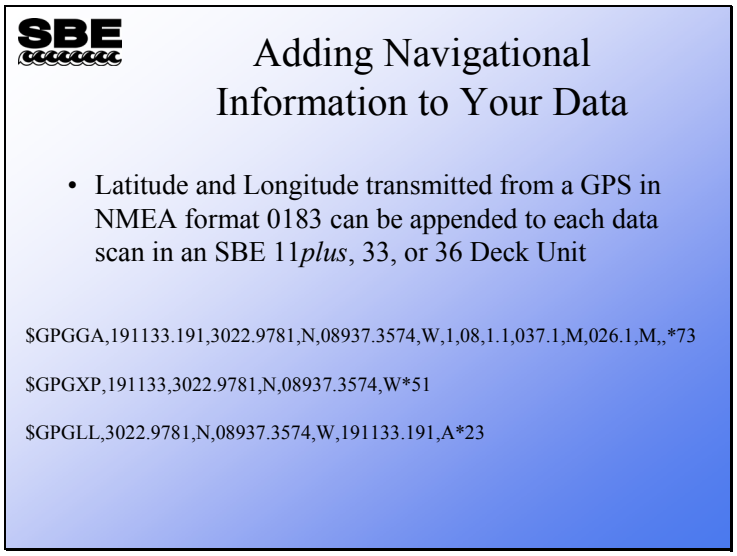
Sound velocity (SV) sensors measure the flight time of a pulse of sound between transducers. To meet the ± 0.05 m/s specification of a typical 20 cm path SV sensor, the time of flight must be measured to within about 4 nanoseconds. The electronics to perform this are difficult but feasible; however, the time delays associated with the acoustic transducers cannot be maintained over pressure and temperature.

While the dependence of SV on time and distance implies that calibration is not required, in practice the distance (within necessary accuracy of 20 cm * [0.05 m/sec/1500 m/sec] = 0.0007 cm = 0.007 mm, at nominal 1500 m/s SV) cannot be established from a physical measurement of path length. This is not caused by uncertainties in mechanical dimensions; but by uncertainties in how deep into the acoustic transducer the sound pulse is when the electrical signal is generated. Accordingly, all direct SV sensors are bath-calibrated (against a CTD or the usual references used to calibrate CTDs - SPRT, Autosal, etc.).

To meet a 0.05 m/s specification, a CTD can be wrong in temperature by 0.028 °C; in salinity by 0.04 PSU; and in pressure by 3 decibars.

The linkage between CTD and SV (Chen and Millero) is part of the equation of state 1980. This international usage and recognition not only leads to the highest level of accuracy, but ensures that CTD-based SV measurements are intercomparable no matter where and when taken.

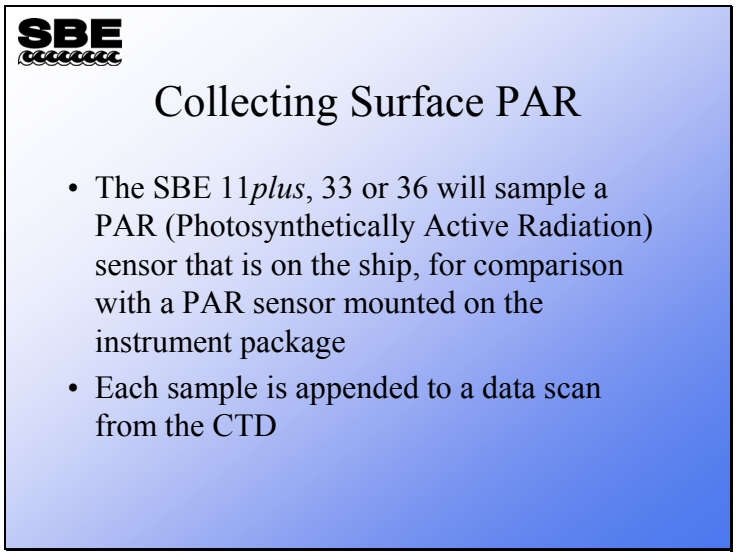
Adding Navigational Data



In Seasave, navigational data transmitted in NMEA format 0183 is appended to real-time data if you select *NMEA position data added* in the instrument configuration (.con) file dialog box. Navigational data is also added to the file header at the start of the cast. And, navigational data can be written to a separate .nav file at user-selected points in the cast.

A NMEA interface is available in all Sea-Bird deck units – SBE 11*plus*, 33 (NMEA interface optional), and 36. The *Seacat/Sealogger RS-232 and Navigation Interface Box* (sometimes called the NMEA Interface Box or Opto-Box) that is used with internally recording instruments or the SBE 21 thermosalinograph also has a NMEA interface.

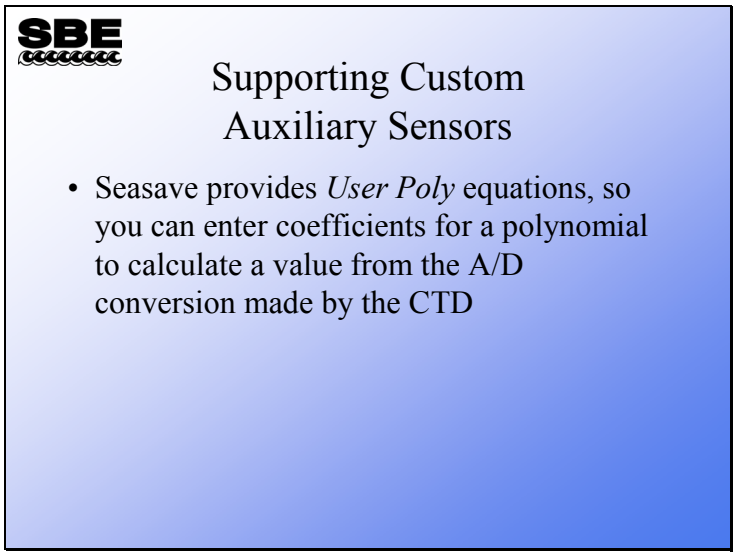
Adding Surface PAR



Sea-Bird deck units may be equipped with an A/D interface intended to digitize the signal from a deck-mounted PAR sensor. This is standard equipment for the SBE 11*plus* and optional for the SBE 33 and 36. In Seasave, Surface PAR data is appended to real-time data if you select *Surface PAR voltage added* in the instrument configuration (.con) file dialog box.

The deck-mounted PAR sensor is used in conjunction with a PAR sensor mounted on the instrument package.

Supporting Custom Auxiliary Sensors



For instruments that are not supported in Seasave, a meaningful display of data can be made by specifying a *user polynomial* to be applied to the 0 – 5V data. The user polynomial can be up to 3rd order:

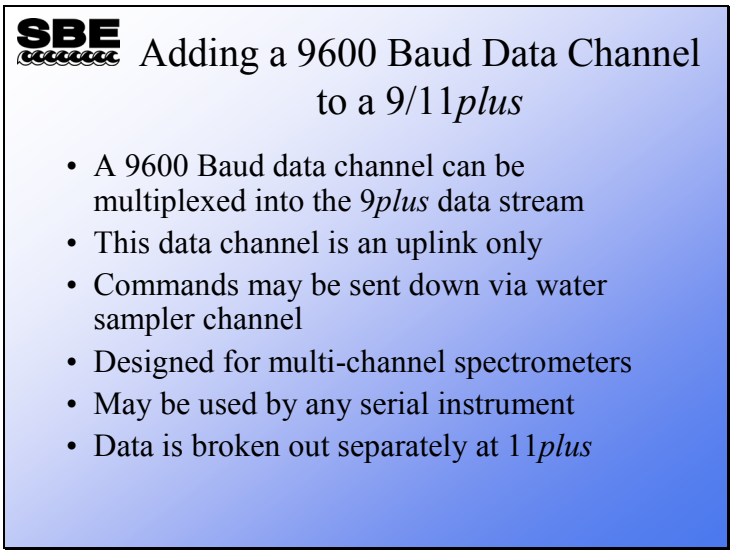
$$Val = a0 + (a1 * V) + (a2 * V^2) + (a3 * V^3)$$

where:

V = voltage from sensor

a0, a1, a2, and a3 = user-defined sensor polynomial coefficients, specified in the instrument configuration (*.con*) file

Adding 9600 Baud Data Channel to 911*plus*



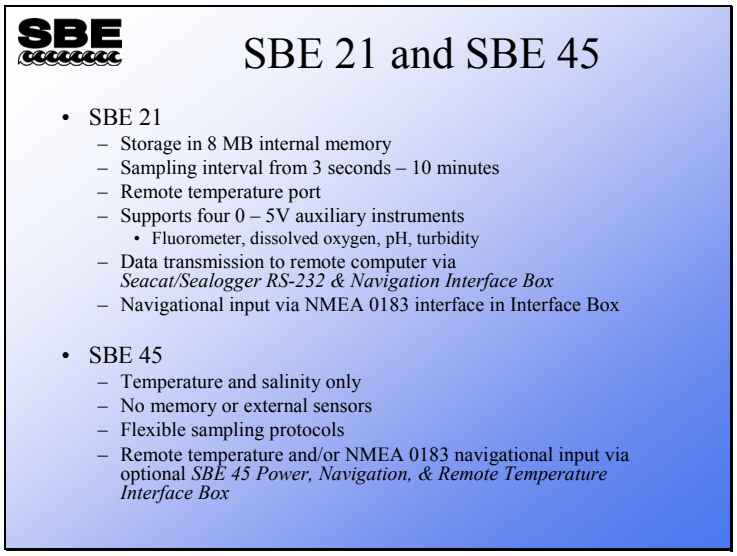
As optional equipment, a 9600-baud serial channel can be multiplexed into the 9*plus* data stream, allowing external instruments that transmit serial data at 9600 baud or less to send their data up the sea cable. This data channel was designed for multi-channel spectrometers; however, it has also been used with acoustic Doppler current meters.

The 9600 baud channel can also be used with an instrument that transmits at 19200 baud in *burst* mode, so that the overall rate of transmission does not exceed 9600 baud.

Thermosalinographs

Thermosalinographs are used to collect information about the sea surface; typically in flow-through systems operating continuously throughout a cruise. They are included in the profiling section of the course because they are installed on many research vessels. Thermosalinographs are typically installed inside and near to the hull of a ship in order to make measurements on uncontaminated seawater. Optionally, you can plumb other types of sensors into the system for a wider range of measurements.

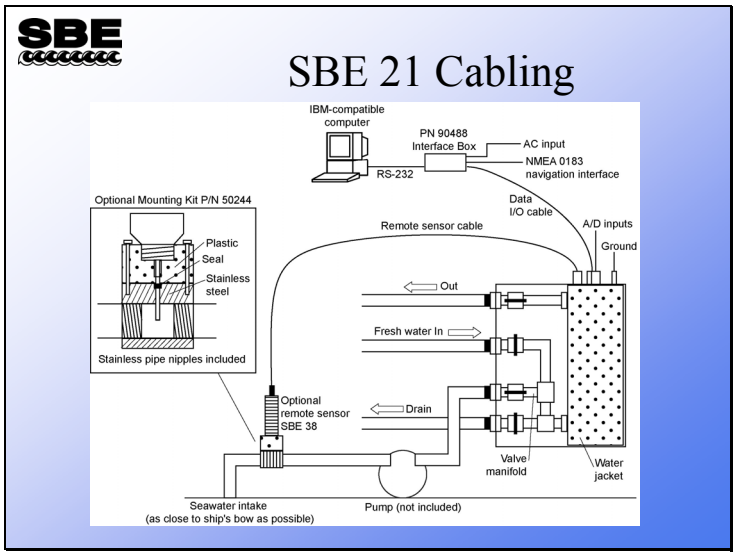
Thermosalinographs (*continued*)



The SBE 21 is the more capable of Sea-Bird's thermosalinograph offerings, supporting a variety of auxiliary sensors and a remote temperature sensor, which is used when the thermosalinograph cannot be mounted close to the sea water inlet. The remote sensor allows a temperature measurement to be made on water that has not been warmed or cooled by a long trip through a pipe. Salinity, of course, does not change with temperature, so the conductivity measurement is valid even though the water may have changed temperature on its journey to the thermosalinograph. The SBE 21 also comes with an Interface Box, which accepts navigational data and appends the data to the SBE 21's data stream.

The SBE 45 does not have the capability to directly integrate remote temperature or navigational data. However, the SBE 45 can be used with an optional Interface Box, which accepts remote temperature and navigational data, and appends the data to the SBE 45's data stream.

Thermosalinographs (*continued*)



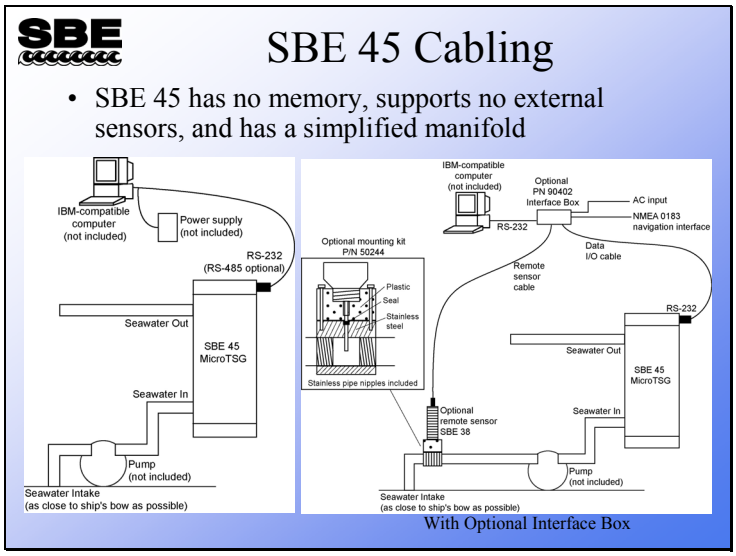
If you want to include navigational (GPS) information in your thermosalinograph data record, you will have to use a *PN 90488 Seacat/Sealogger RS-232 and Navigation Interface Box* (sometimes called an *Opto-Box* or *NMEA Interface Box*) and log your data with Seasave. The GPS data is very useful for mapping sea surface conditions. The *Interface Box* provides power and melds the SBE 21 data with the GPS data. Because the GPS data cannot be input directly to the SBE 21, you must devote a computer to data collection via Seasave.

Thermosalinographs (*continued*)

SBE 21 Setup and Memory Endurance

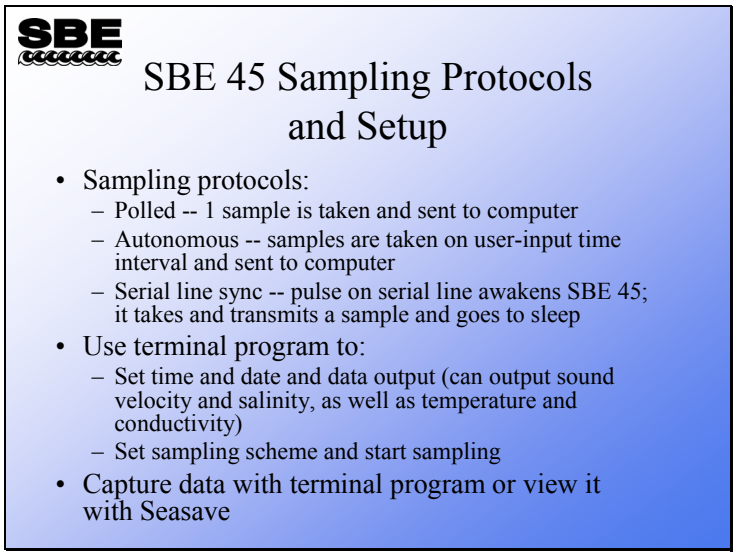
- Use terminal program to:
  - Set time and date, and external sensors to log
  - Set sampling scheme and sample interval – continuous at 4 Hz (averaging every *sample interval* seconds) or 1 sample every *sample interval* seconds
  - Begin sampling with **GL** command
- Capture data with terminal program or view it with Seasave
- SBE 21 comes with 8 Mbytes of memory
  - Temperature and conductivity require 4 bytes
  - Each voltage adds 1.5 - 2 bytes (6 bytes total for 4 voltage inputs)
  - Remote temperature adds 3 bytes
- SBE 21 continues to transmit after memory is full
- Inter-record headers are written at 1000 scan intervals

Thermosalinographs (*continued*)



As mentioned previously, the SBE 45 does not have the capability to directly integrate remote temperature or navigational data. However, it can be used with an optional Interface Box, which accepts remote temperature and navigational data, and appends the data to the SBE 45's data stream.

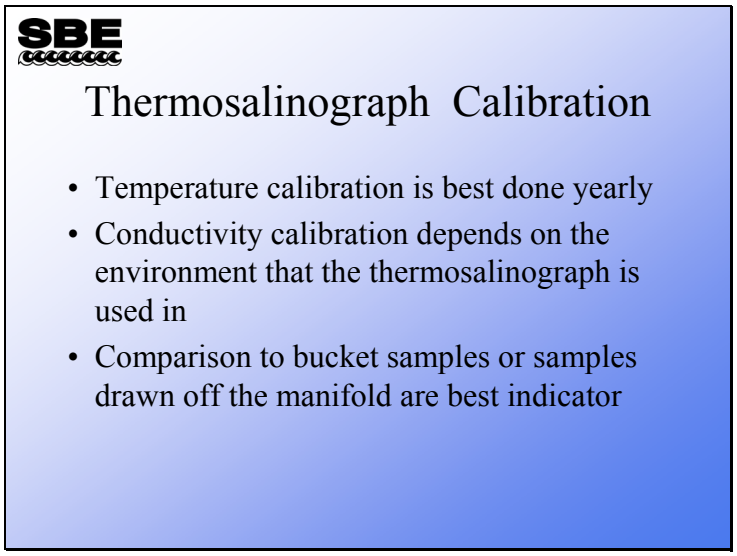
Thermosalinographs (*continued*)



The SBE 45 offers three sampling modes:

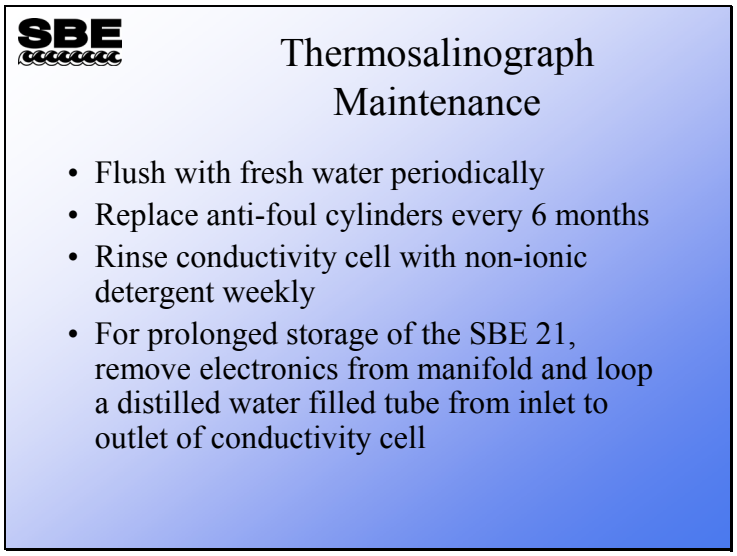
- Your computer can ask for a sample; the SBE 45 will take one sample and send it to your computer.
- The SBE 45 will sample at regular intervals and transmit the data.
- A pulse on the serial line (your computer sends a character) causes the SBE 45 to send a sample.

Thermosalinographs (*continued*)



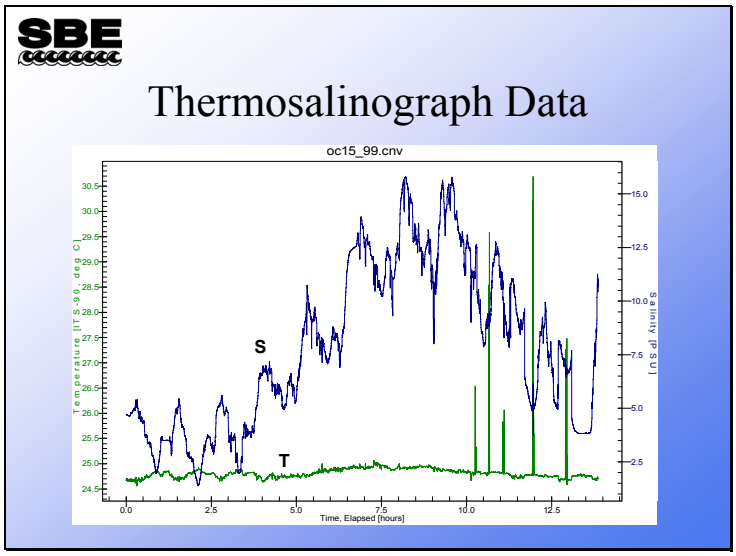
These are recommendations only; the conductivity calibration depends on the environment that the thermosalinograph is operated in.

Thermosalinographs (*continued*)

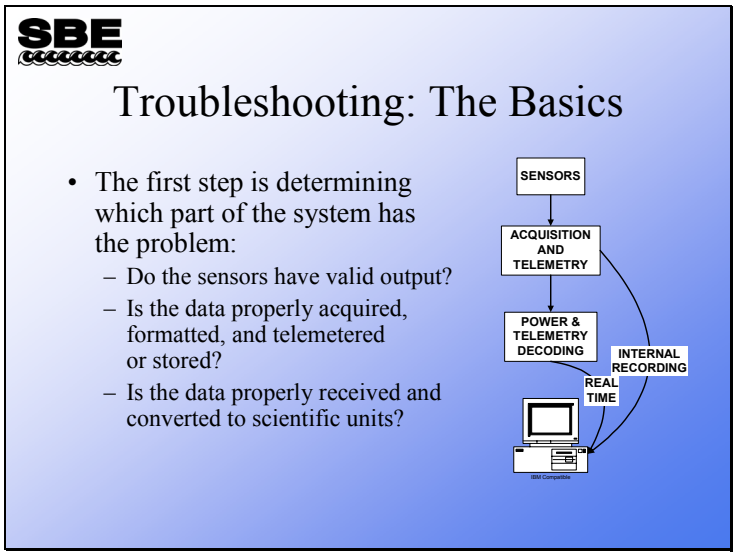


If you have a great deal of biological activity, you should provide more care for your thermosalinograph. Organisms really like pumped systems because they can settle in and have a 24-hour constant flow of seawater past them; it is *little-creature heaven*. Harbors and coastal areas tend to have more contaminants in the water. Use the bucket samples discussed in the last slide to decide when to clean and calibrate you equipment.

Thermosalinographs (*continued*)

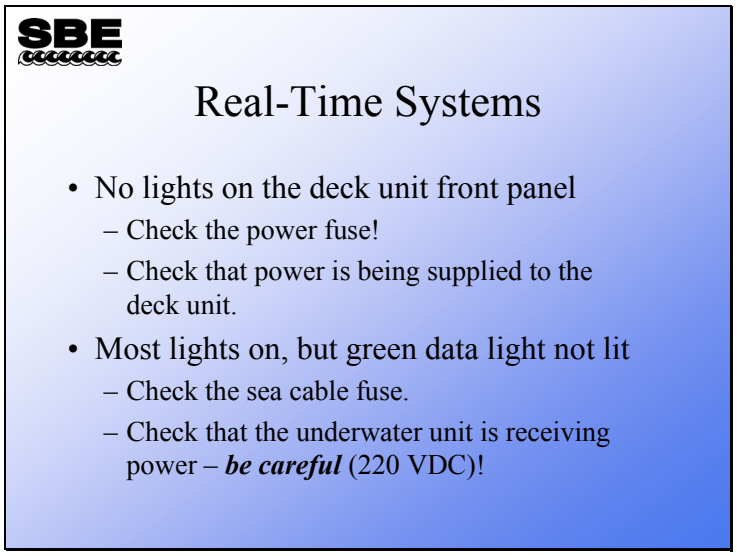


Troubleshooting



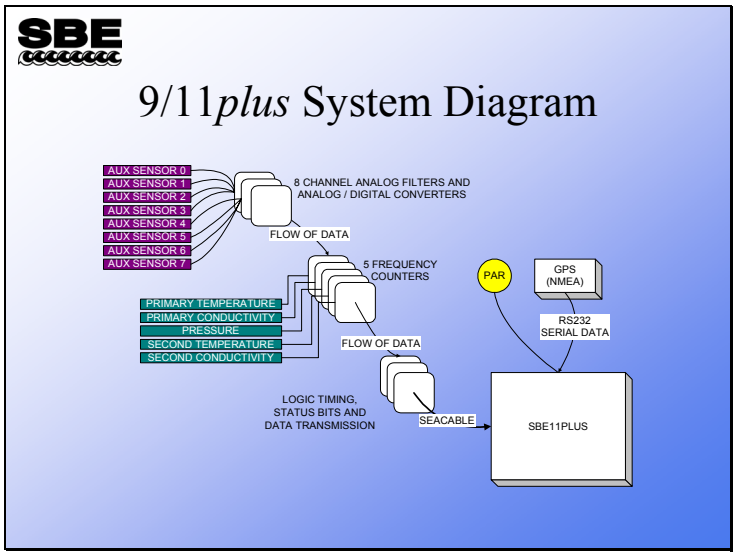
Next we will discuss troubleshooting. Troubleshooting is an art based on a fundamental understanding of the way your equipment is supposed to work. We will attempt to cover the most common problems in this broad topic, ranging from problems with electronic circuits to mechanical parts that need to be cleaned.

Troubleshooting: Real-Time Systems



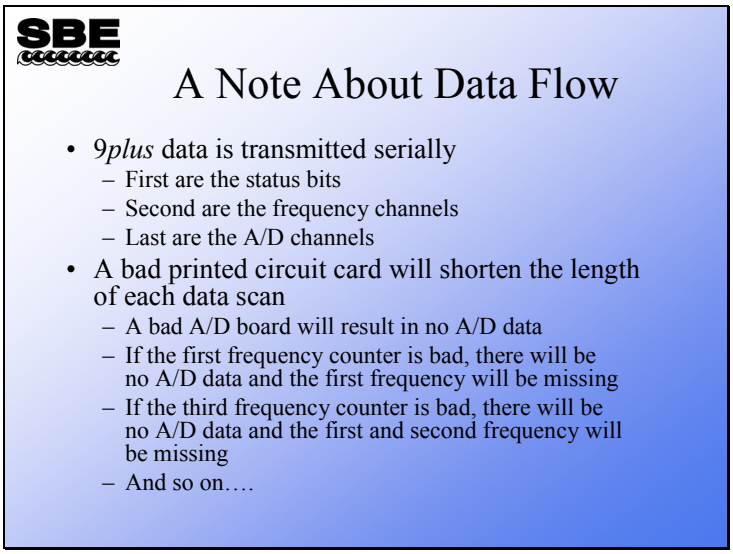
After the obvious things, like checking the fuse and the power outlet the deck unit is plugged into, check that the underwater unit is receiving power. If you disconnect the sea cable underwater connector from the CTD, you should find a large DC voltage (150 – 250V) between the large pin and the small pin. Note that the large pin is ground. Real-time systems that are running via an *Interface Box or Opto-Box* will have only 10 – 15 volts across the sea cable connector.

Troubleshooting: 911*plus*



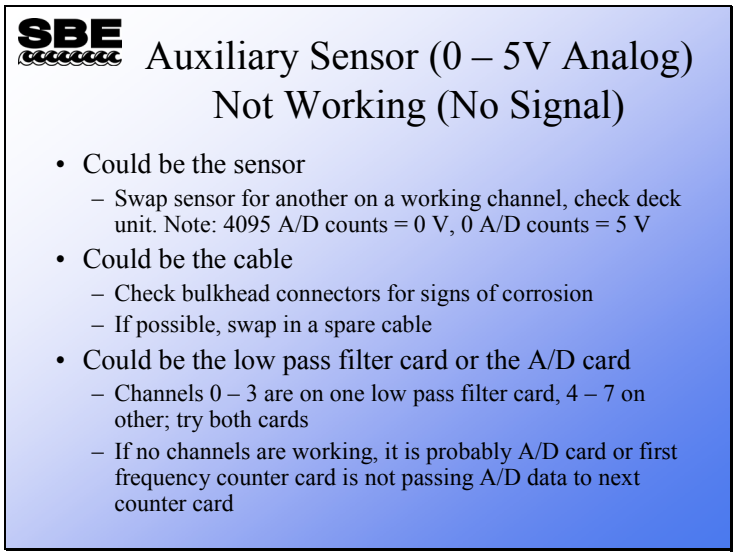
The 9/11*plus* is a highly modular system. You can exploit this characteristic of the instrument in troubleshooting. You can swap sensors, swap cables, and if necessary, swap printed circuit boards to see if trouble follows any one of these components.

Troubleshooting: 911*plus* (*continued*)



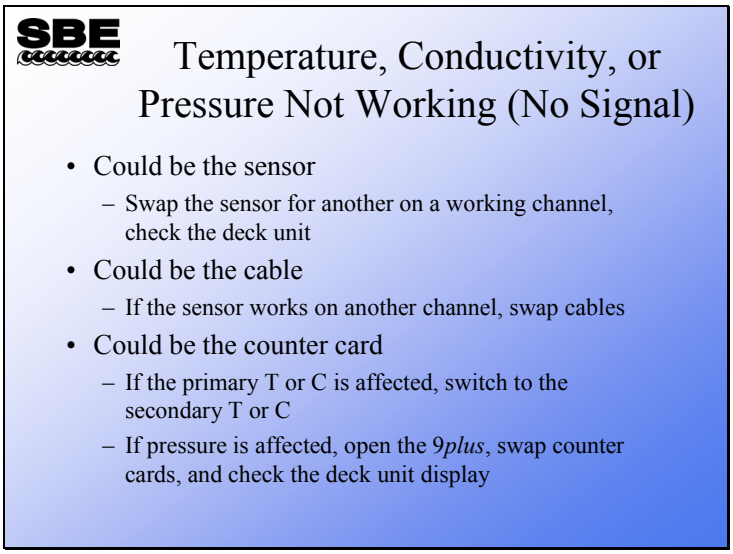
The 9*plus* transmits its data serially. A sensor, or in the case of analog channels a group of sensors, is measured and the data is passed from one circuit board to the next and through the output section onto the sea cable. Therefore, if one PCB malfunctions, the data from all the cards below it will be missing from the data stream. You can check out each channel in the data stream via the 11*plus* front panel display.

Troubleshooting: 911*plus* (*continued*)



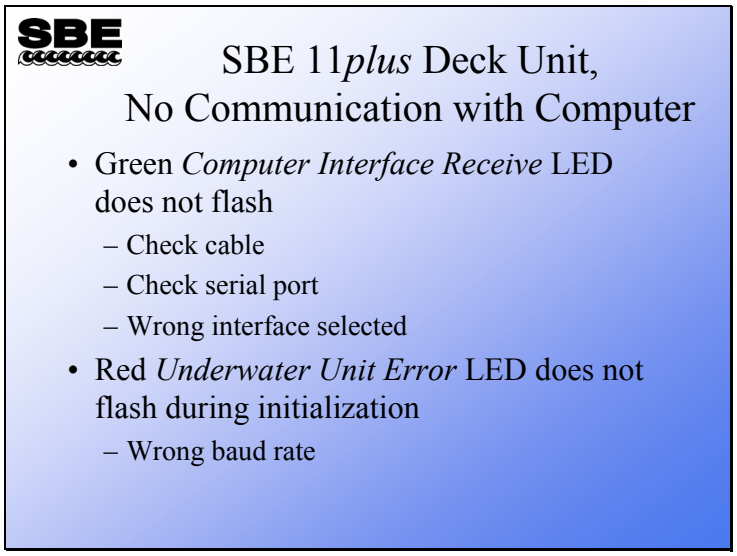
The front end of the analog-to-digital system consists of 2 printed circuit boards with 4 channels on each. If you have problems in one channel, switch to the other analog input card. If the problem disappears, it is in the analog input PCB. If the problem persists, it may be in the analog-to-digital conversion PCB.

Troubleshooting: 911*plus* (*continued*)



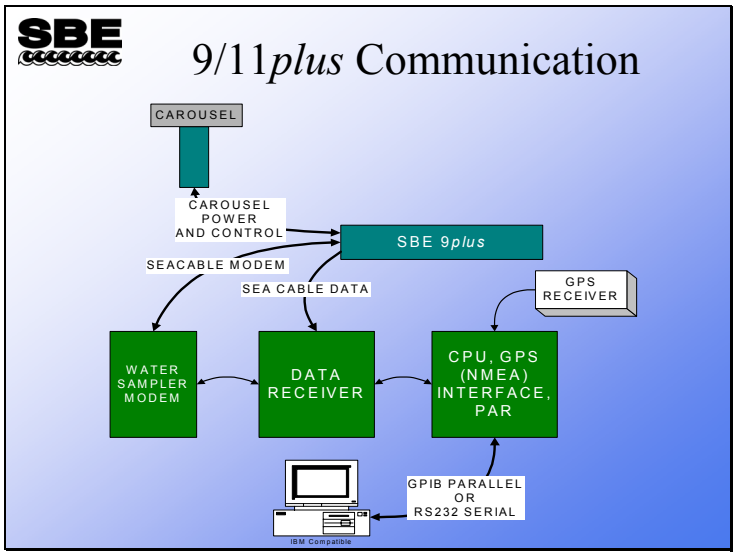
Similarly, there are 5 frequency channels in the 9*plus*. These are interchangeable; you can quickly isolate a problem in the CTD section of the instrument by swapping cables and counter channels. By doing this you can determine if the problem lies with a sensor, a cable, or a counter card.

Troubleshooting: 911*plus* (*continued*)



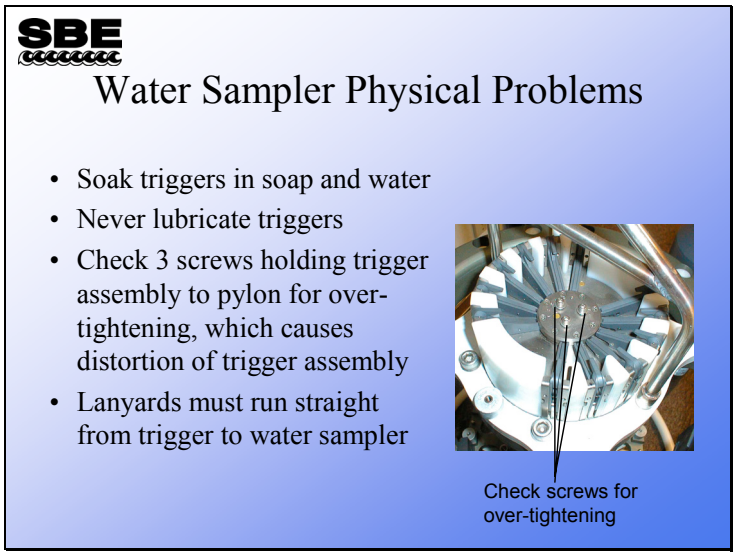
In considering the deck unit end of the system, first look to the cabling between the PC and 11*plus*. When Seasave starts, it communicates setup information to the 11*plus*. This data transmission causes the 11*plus Computer Interface Receive* LED to flash. If the 11*plus* is correctly receiving the setup information, the computer interface red *Underwater Unit Error* light will flash briefly during this time. If the red *Underwater Unit Error* LED does not flash, the baud rate is not correctly set in the *COMM Port Configuration* dialog found on the *Acquire and Display Real -Time Data Set Up* dialog in *Seasave*.

Troubleshooting: 911*plus* (*continued*)



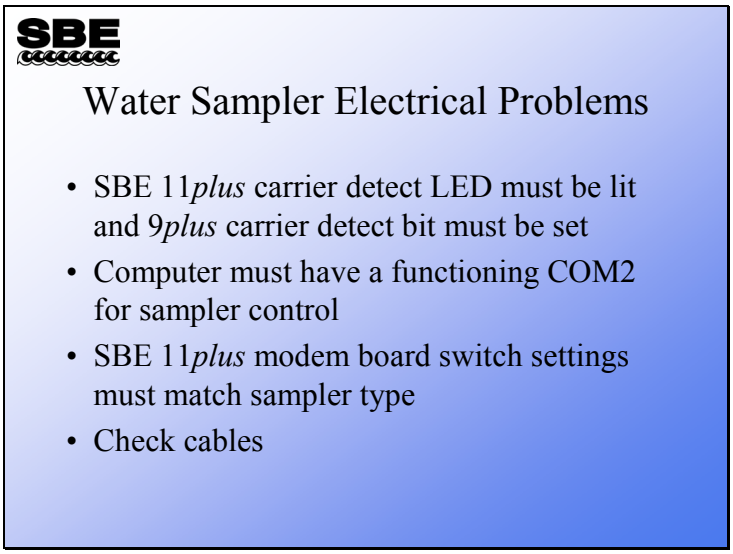
Here is a signal flow diagram for the circuit boards in the 11*plus*, the 9*plus*, the Carousel, and your PC. Note that water sampler commands pass from your computer to the 11*plus* CPU board, to the receiver board, to the modem board, to the 9*plus*, and into the Carousel.

Troubleshooting: Carousel Water Sampler



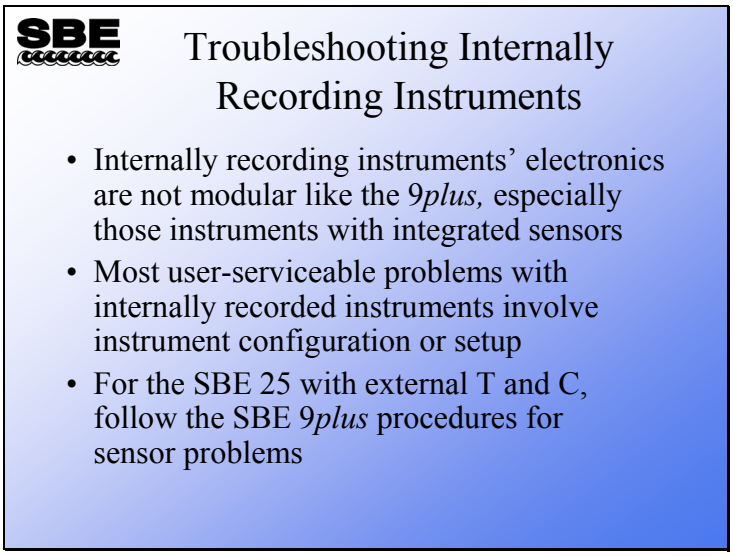
Many general water sampler problems such as *bottles don't close* can be traced to physical problems with the sampling system. The Carousel triggers are coated with an oxide-type layer that is meant to water lubricate. The coating absorbs oil and becomes gummed up and sticky. Often, giving the triggers a good soak in hot soapy water will return them to their original state. Conversely, honing the latch parts to remove the coating will remove the lubricating layer and make them more susceptible to sticking. If you do remove your triggers for cleaning, be sure that you don't over tighten the three screws that hold the triggers to the magnet assembly. Over tightening will cause the trigger plates to warp and will cause the triggers to bind.

Troubleshooting: Carousel Water Sampler (*continued*)

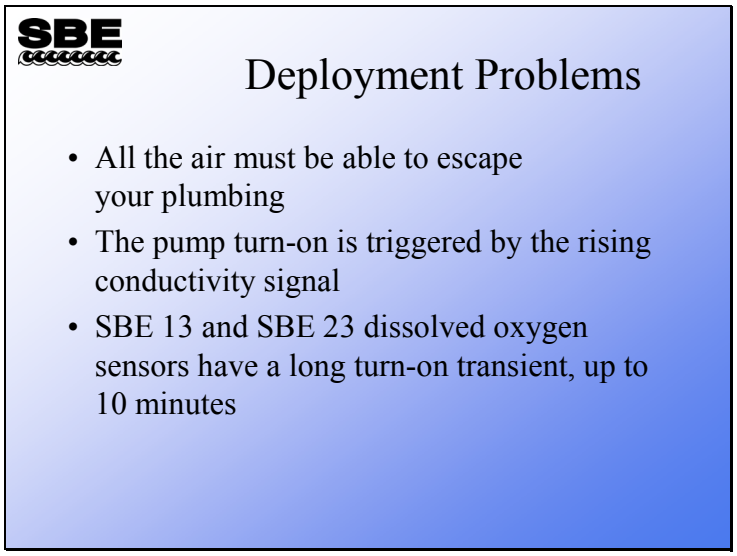


Water sampler control is carried out over a 300-baud modem channel. This channel is full duplex (both up and down communication) and shares the wire with the main data channel. Indications that the 9/11*plus* system has proper modem communication are found on the front panel of the 11*plus* and in the status bits of the 9*plus*. If the 11*plus* modem carrier frequency is detected in the 9*plus*, a status bit is set. If the 9*plus* carrier frequency is detected in the 11*plus*, a carrier LED is lit. For the SBE 33 Carousel deck unit, an LED flashes when communication is received from the SBE 32 Carousel.

Troubleshooting: Internally Recording Instruments



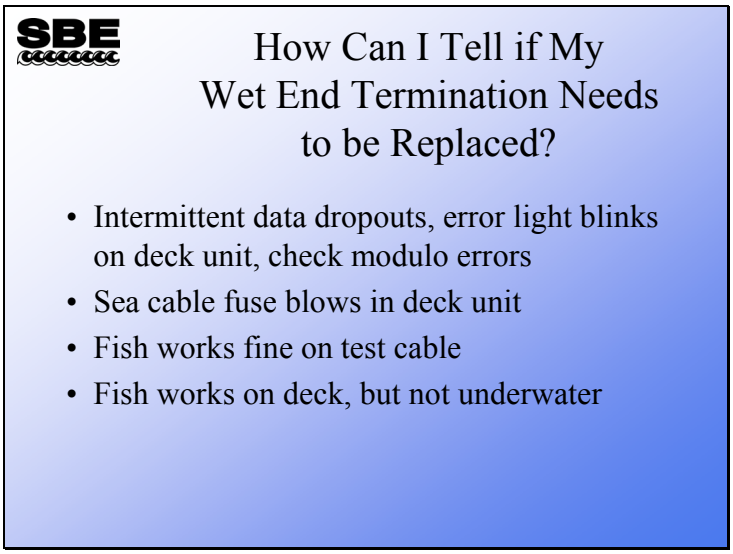
Troubleshooting: Deployment Problems



A lot of deployment problems can be avoided by being careful when you prepare your instrument for deployment and by being patient and waiting for a surface soak.

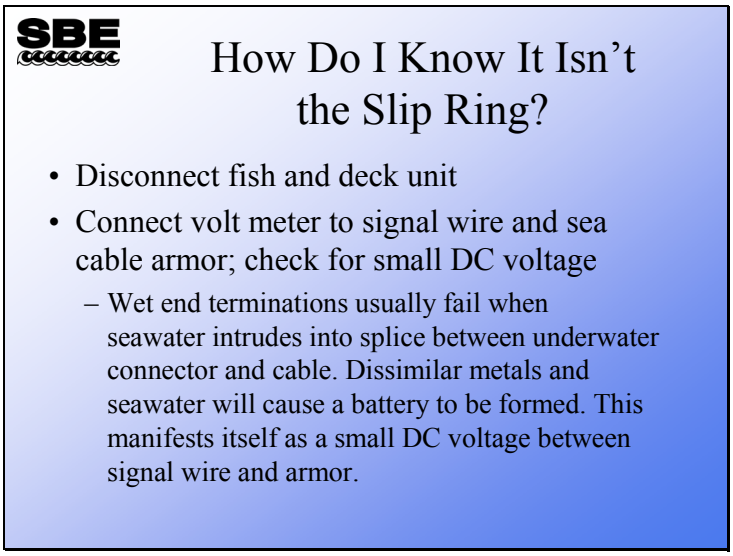
- Secure loose cables and make sure your plumbing is going to properly vent air.
- Soak your instrument package near the surface for at least 2 -3 minutes before lowering away. If you are using an older dissolved oxygen sensor, soak for 10 minutes to ensure the electrode is properly polarized before beginning your cast.

Troubleshooting: Deployment Problems (*continued*)



The part of the sea cable that connects to the instrument package receives a lot of wear and is under a great deal of stress. The cross-sectional area of most instrument packages causes a huge load on the cable every time the ship rolls. The 9*plus* data stream has an 8-bit counter that increments at each data scan, returning to 0 after 255. Missing scans show up as a missing number in the count. Because decoding the 9*plus* counters requires a scan and the scan before it, missing scans show up as data spikes. Usually, data errors of this sort are caused by intermittent connection in the mating end of the sea cable.

Troubleshooting: Deployment Problems (*continued*)



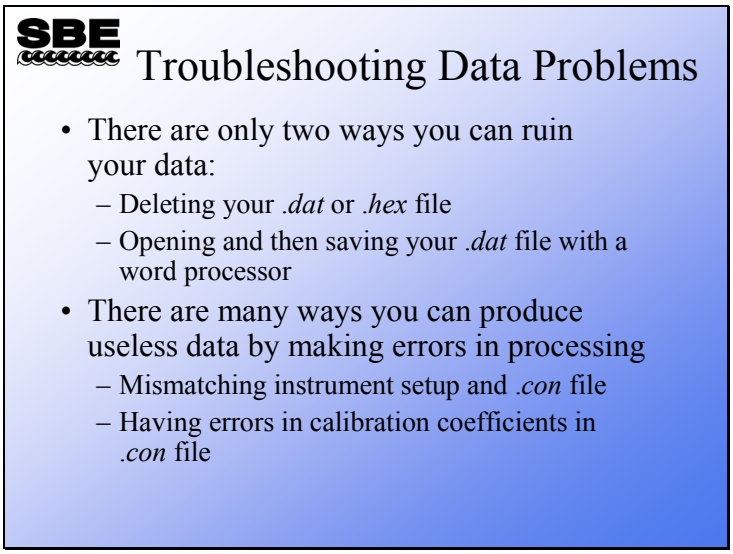
Like other troubleshooting activities, the solution here is *divide and conquer*. Check the sea cable as described above. If everything seems normal, disconnect the slip-ring from the sea cable and the cabling that runs into the computer room. The slip-ring should present very low resistance on all of its conductors through a whole rotation. Switch to another conductor if you find one that has high resistance or becomes intermittent.

Troubleshooting: Deployment Problems (*continued*)

Why Can't I Use the Ohm Setting on My Multimeter?

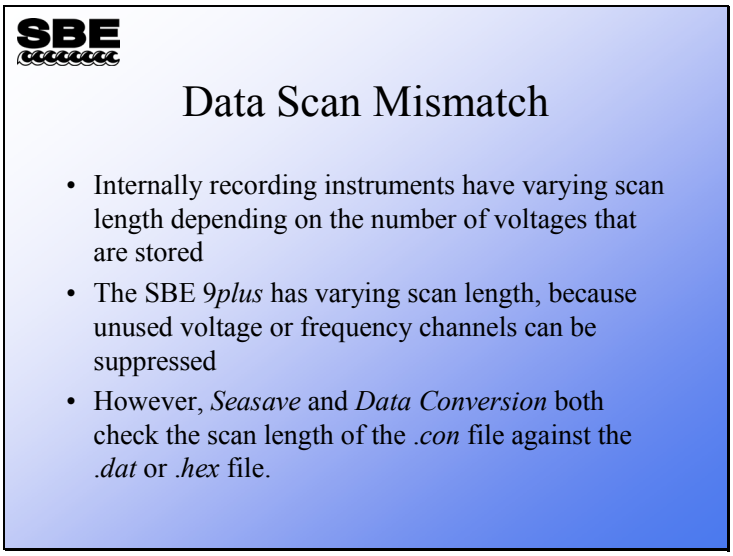
- You can BUT:
  - 10 kilometers of cable has capacitance, and when wound on winch spool may have some inductance
  - These properties can give confusing readings on your multimeter in Ohm setting

Troubleshooting: Data Problems



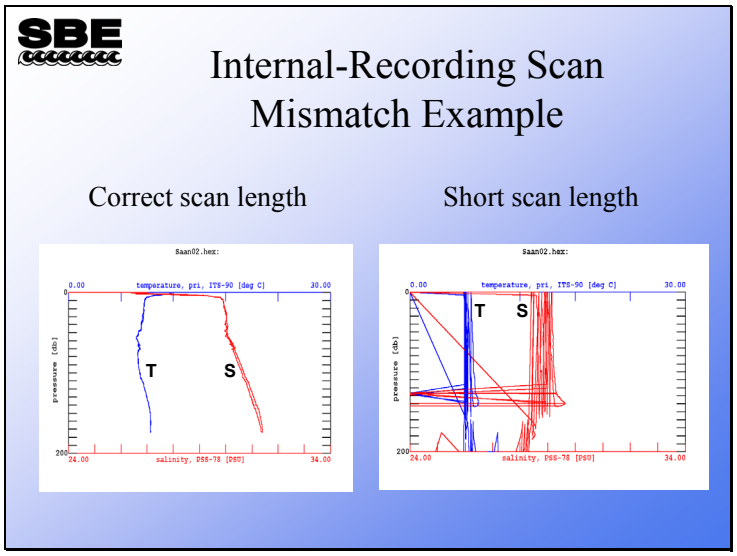
As we mentioned earlier, older (<6.0) versions of Seasave created a .dat file for data from an SBE 911*plus*. Versions 7.0 and later create a .hex data file for data from all supported instruments.

Troubleshooting: Data Problems (*continued*)

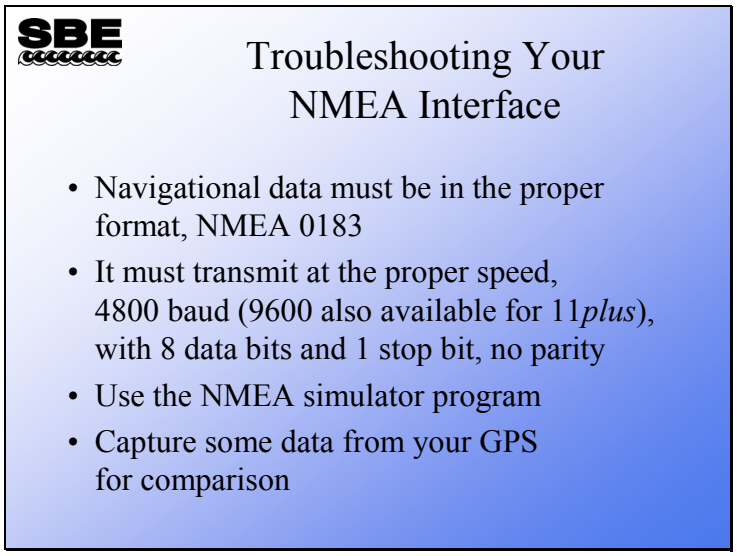


You can only harm yourself with data scan mismatch with internally recording instruments. It is always good idea to take a look at your data before you initialize (erase) the memory in your internally recording CTD.

Troubleshooting: Data Problems (*continued*)

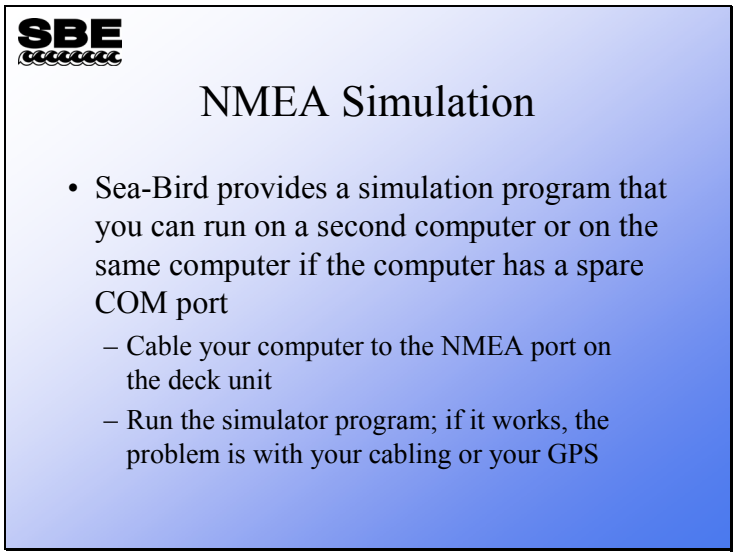


Troubleshooting: NMEA Problems



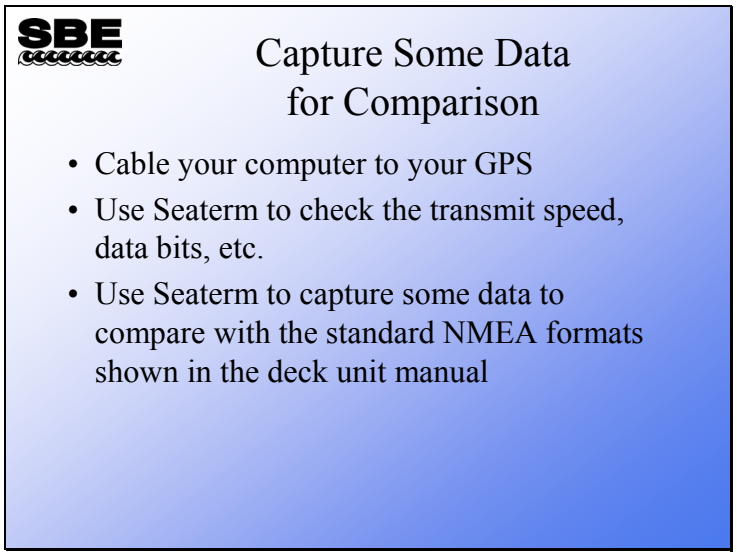
Adding navigational information to your data can be troublesome. Manufacturers of GPS receivers are not scrupulous in following the NMEA data format. You can check the transmit rate, data bits, and parity as well as output format of your GPS with your PC and a terminal program. If these don't match the NMEA standard, then you may not get latitude and longitude appended to your data. If you think that there is a problem with the deck unit receiving data, you can use your PC and the simulation program found in Seasoft. NMEA and GPS installation and troubleshooting is discussed in detail in the deck unit(s) manual.

Troubleshooting: NMEA Problems (*continued*)



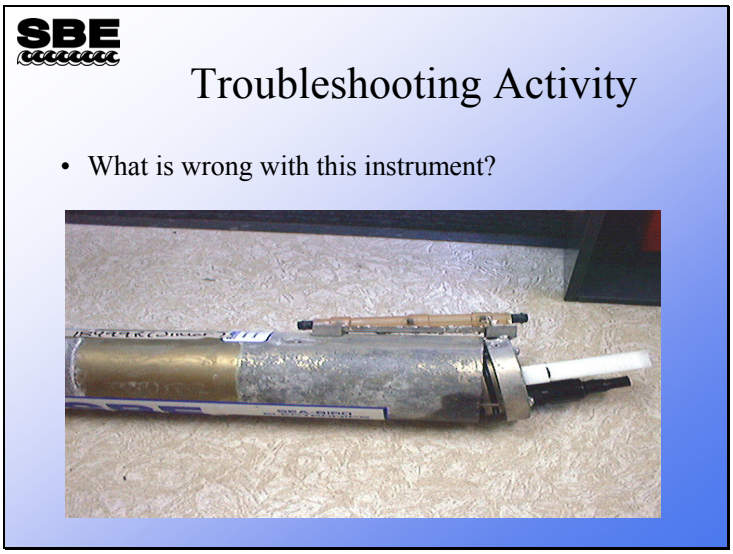
You can test the deck unit and Seasave with the NMEA simulation program, NMEATest. Cable the NMEA port on the deck unit to a second PC with the provided cable. Alternatively, you can run the simulation using only one computer if the computer has a spare COM port. The simulation program sends NMEA messages in the RMA, RMC, GGA, or GLL format.

Troubleshooting: NMEA Problems (*continued*)

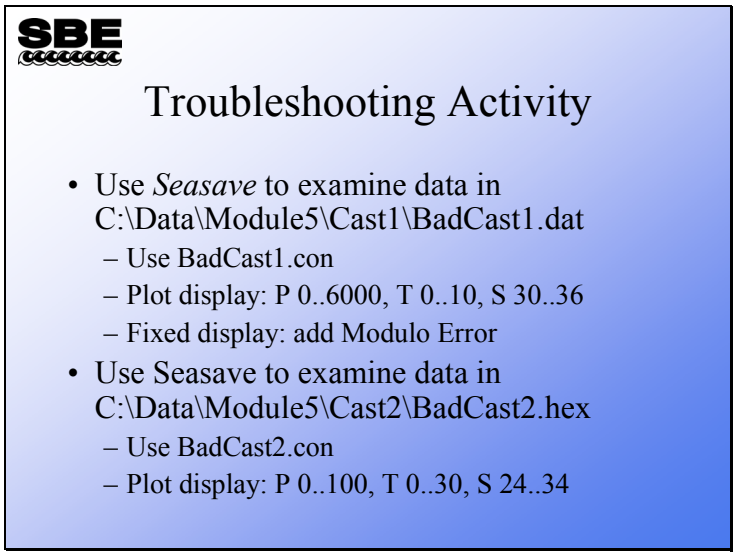


Standard NMEA data formats are shown in the deck unit manual. You can use the capture facility to collect some data from your GPS. If the data is not in the proper format, check your GPS manual to determine the configuration that will yield the correct data format.

Activity


SBE
Troubleshooting Activity
• What is wrong with this instrument?

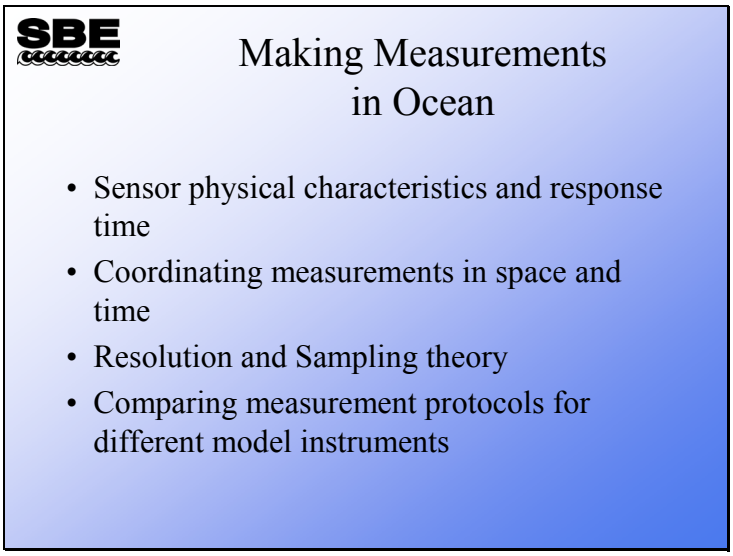
Activity


SBE
Troubleshooting Activity
• Use Seasave to examine data in C:\Data\Module5\Cast1\BadCast1.dat
– Use BadCast1.con
– Plot display: P 0..6000, T 0..10, S 30..36
– Fixed display: add Modulo Error
• Use Seasave to examine data in C:\Data\Module5\Cast2\BadCast2.hex
– Use BadCast2.con
– Plot display: P 0..100, T 0..30, S 24..34

Module 6

Making Measurements in the Ocean

Overview

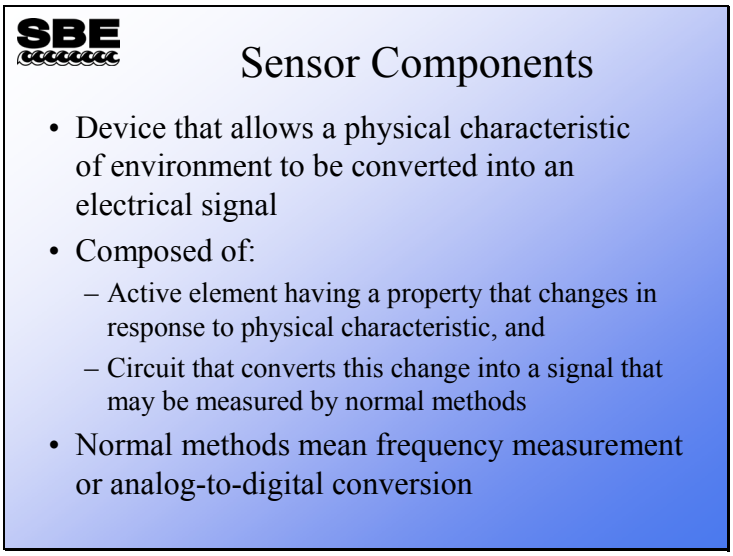


In this section we will take a close look at how measurements are made, in the environment in general and in the ocean specifically. We will discuss what to expect from measurements in terms of resolution and how to judge if we can make the measurements needed for our scientific purpose with the equipment at hand. Many common oceanographic parameters, such as salinity or density, require measuring multiple physical parameters, such as temperature and conductivity, to calculate the single new parameter. We will consider how measurement techniques impact the accuracy of these parameters.

At the end of this module, you should be able to:

- Determine what resolution your data will have, based on instrument sampling rate and descent rate in the ocean.
- Describe what a sensor is and how it operates.
- Explain the importance of correlating temperature, conductivity, dissolved oxygen, and pressure measurements in time and space.

Sensors Revealed



Sensors convert a physical property of the environment into an electrical signal. Variations in the physical property are followed by variations in the signal. Consider a telephone, which converts the pressure wave that is sound into an electrical signal that can be transmitted through a wire. In similar fashion, oceanographic sensors convert pressure, temperature, conductivity, or some other physical parameter into varying electrical signals that are proportional to the value of the physical parameter. Typically, a sensor is composed of two parts:

- Active element

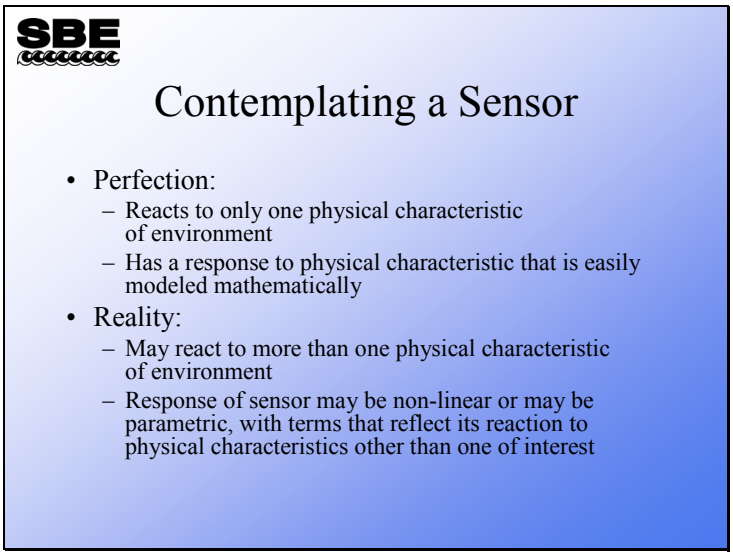
  The active element converts the physical parameter of interest into an electrical signal. To operate, the active element generates an electrical current or modifies an electrical current in response to changes in the value of the physical parameter.

- Conditioning circuitry

  The conditioning circuitry provides any electronics required for the active element to work. The circuit might use changes in a property of the active element. For example, oceanographic thermometers often use a thermistor to measure temperature. A thermistor changes its resistance to current flow as its temperature changes.

  The circuit might also convert the active element's output into an electrical signal type and range that is more easily converted to digital format. For example, the dissolved oxygen active element has a cathode that reacts with O_2 to produce a weak electrical current; the conditioning circuit converts that current into a 0 to 5V sensor output.

Sensors Revealed (*continued*)



The best sensor has an active element that:

- Reacts only to 1 environmental parameter.

  This is a rather rare occurrence. *Almost any semiconductor or wet electrode will react to changes in temperature and pressure*. Response to multiple environmental parameters is referred to as *non-specific response*.

- Responds to changes in temperature and pressure in a fashion that is easily modeled.
- Responds instantly to changes in the physical parameter.

The problem of non-specific sensor response can be overcome with:

- The housing or mounting arrangement of the active element.

  For example, placing the thermistor of the SBE 3 in a fine needle protects it from pressure effects, but still allows it to react rapidly to changes in ocean temperature.

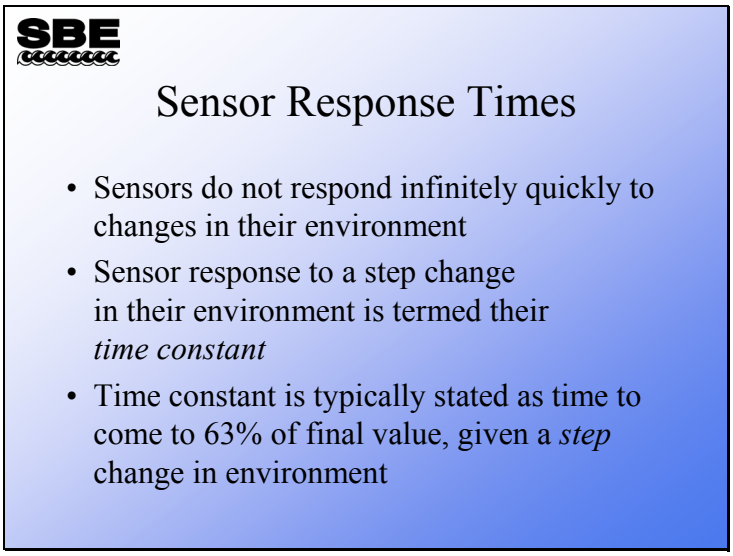
- The conditioning circuitry, which might have elements that compensate for temperature effects within the conditioning circuitry itself.
- The mathematical equation that converts sensor output to scientific units.

  For example, the SBE 4 conductivity sensor is affected by temperature as well as pressure; this is characteristic of the glass used for the cell. The best way to remove these effects is mathematically, turning the calibration equation into a parametric equation that has terms that depend on temperature and pressure.

- A second shielded sensor that compensates for non-specific response.

  For example, pH sensors have an electrode that is measured against a reference electrode contained within the sensor body.

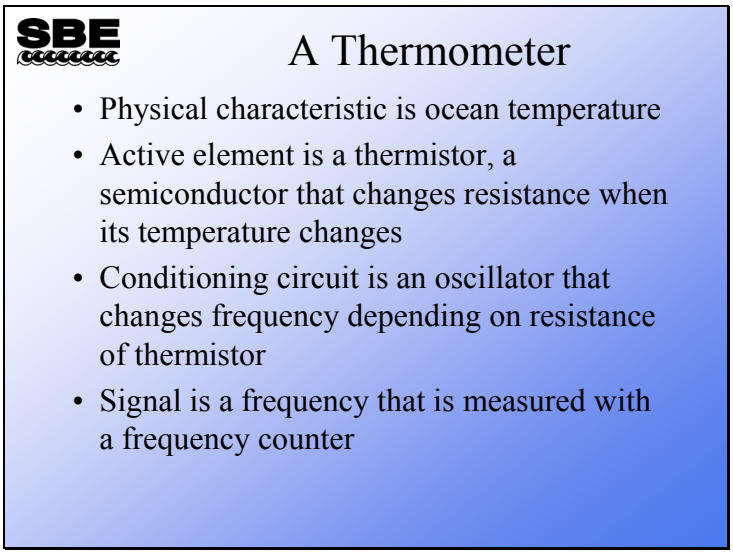
Sensor Response Times



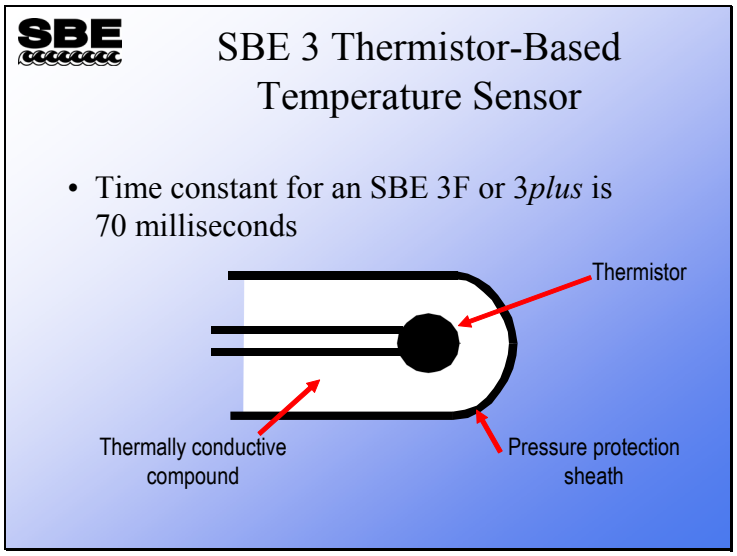
Sensors do not react infinitely quickly to a new environmental condition. For example, let's look at a 2-box ocean, with the top box at 20 °C and the bottom box at 0 °C. If our CTD moved from the top to bottom box, we would see a temperature signal that changed very quickly from 20 °C to 0 °C, but not as a perfectly sharp jump. *The reason for a slower response time for sensors is often found in the packaging of the active element of the sensor.*

For example, a thermistor is housed in a thin metal sheath; the delay in response to a sharp change in temperature from warm to cold is due to the time required for the heat in the thermistor to diffuse into the environment. For a conductivity cell, there is flushing time of the cell. For a dissolved oxygen sensor, there is the time required for the concentration of O_2 near the electrode to equilibrate with the environment. *The time constant, or τ, of the sensor is expressed as the time for the sensor to come to 63% of its final value given a step input.*

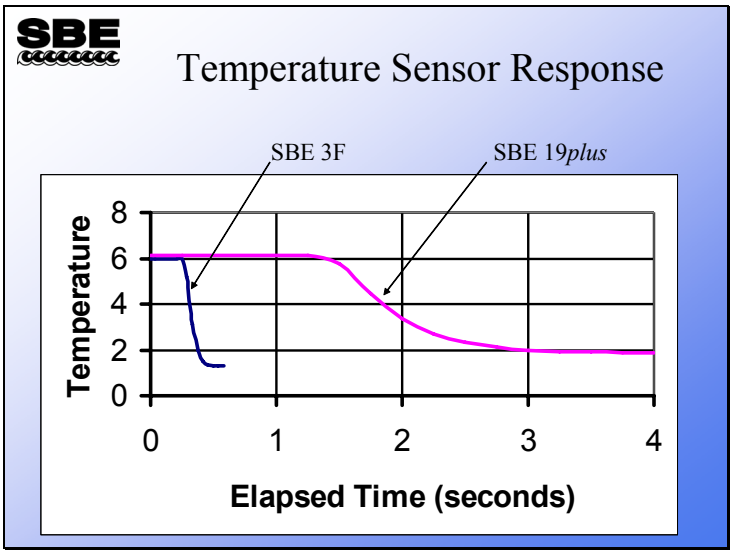
Sensor Example: a Thermometer



Sensor Example: a Thermometer (*continued*)

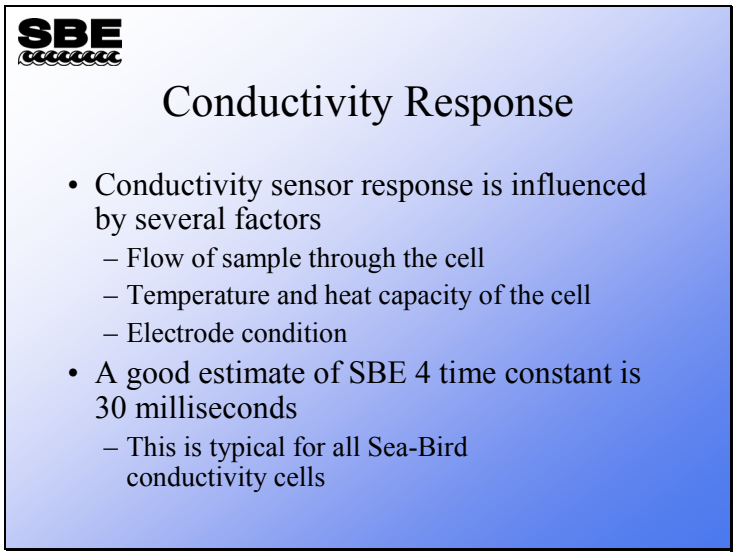


Thermometer Response Comparison



This plot compares the time response of the SBE 3F with the SBE 19*plus*. The SBE 3F has a smaller thermistor and a smaller needle, giving it a faster response time.

Conductivity Sensor Response

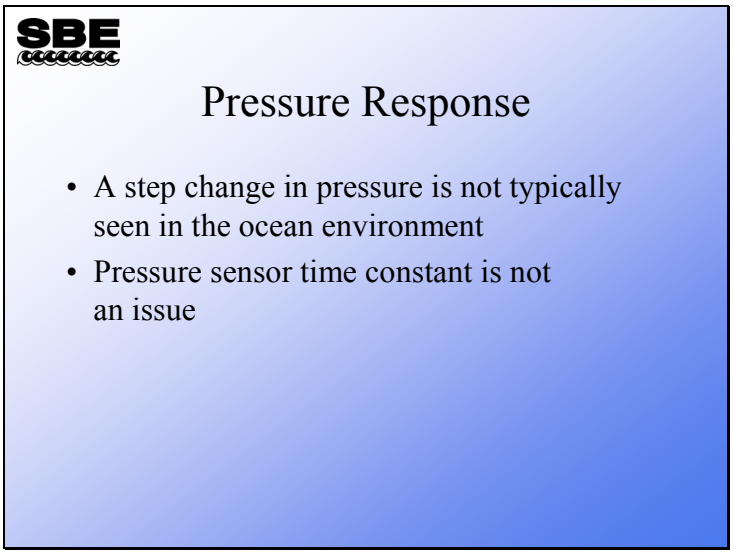


Sea-Bird conductivity cells have an effective volume (*i.e.*, the region within the cell where the conductivity measurement is actually made) of about 2 cm^3. At 30 ml/s, this volume is flushed in 67 ms. The cell response to a step change in conductivity has a sin(x)/x character. Up to the first null (fn at 15 Hz), this response approximates the shape of the temperature sensor's exponential response. For the sin(x)/x function, the half-power point occurs at 0.443fn = 6.645 Hz and conductivity Tau is therefore 1/(2 * pi * 6.645) = 0.024 s. Because of viscous effects that tend to retain boundary layer water, the response measured in laboratory experiments is somewhat longer (0.030 s).

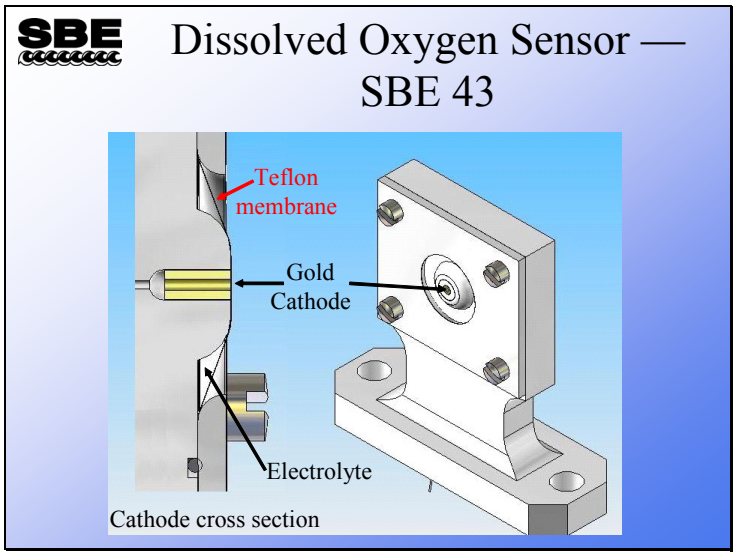
The measurement of a conductivity cell time constant is a difficult problem. Below are some references to papers that have addressed this problem.

- Gregg, M.C.,T. B. Meagher, E. E. Aagaard, and W. C. Hess (GMAH 1981) "A salt-stratified tank for measuring the dynamic response of conductivity probes", IEEE Journal of Oceanic Engineering, vol OE-6, 113-118.
- Gregg, M. C., and W. C. Hess (GH 1985) "Dynamic response calibration of Sea-Bird temperature and conductivity probes", Journal of Atmospheric and Oceanic Technology, vol 2(3), 304-313.

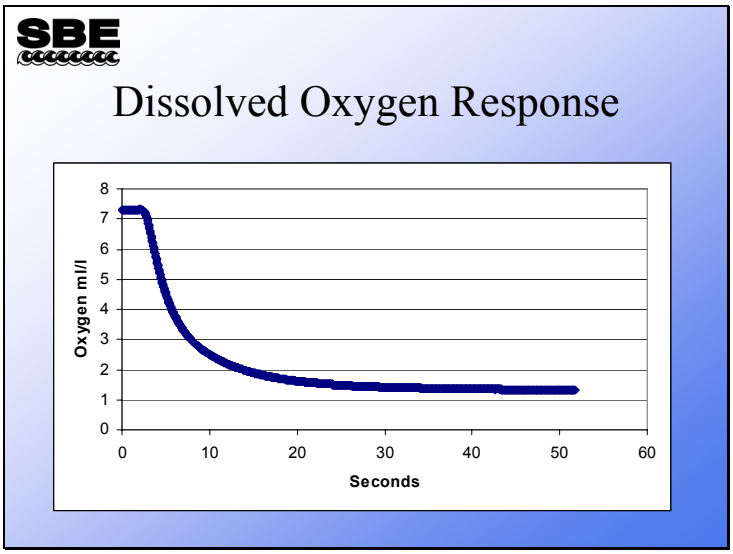
Pressure Sensor Response



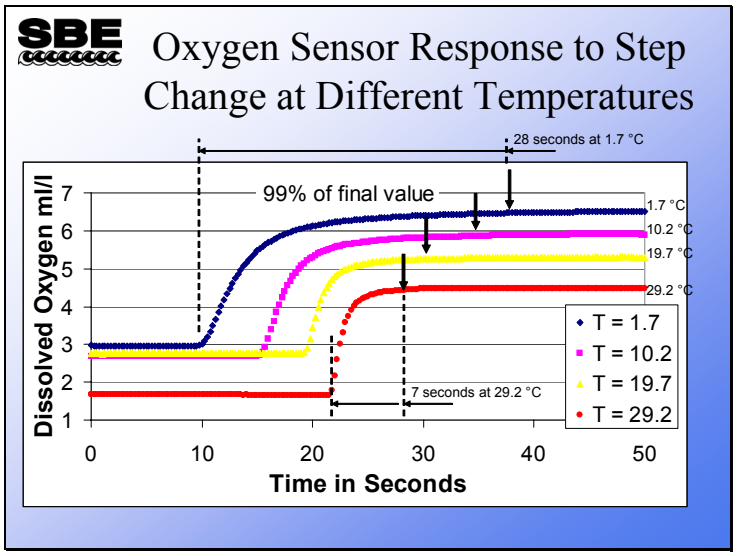
Dissolved Oxygen Sensor



Dissolved Oxygen Sensor Response

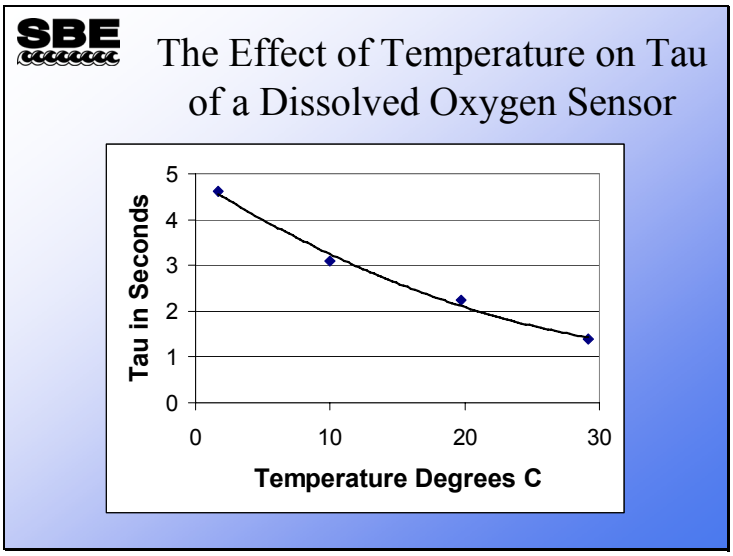


Dissolved Oxygen Sensor Response (*continued*)



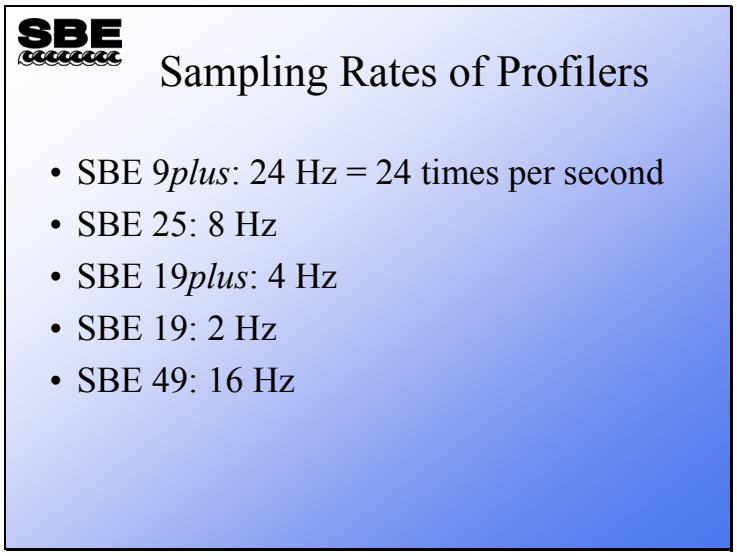
The plot above illustrates the effect that temperature has on a dissolved oxygen sensor. The colder the water that the sensor is working in, the longer it requires to come to a final value. This phenomenon is observable as upcast and downcast hysteresis. We will consider how to lessen this effect with the data processing *Align CTD* module in Module 9.

Dissolved Oxygen Sensor Response (*continued*)



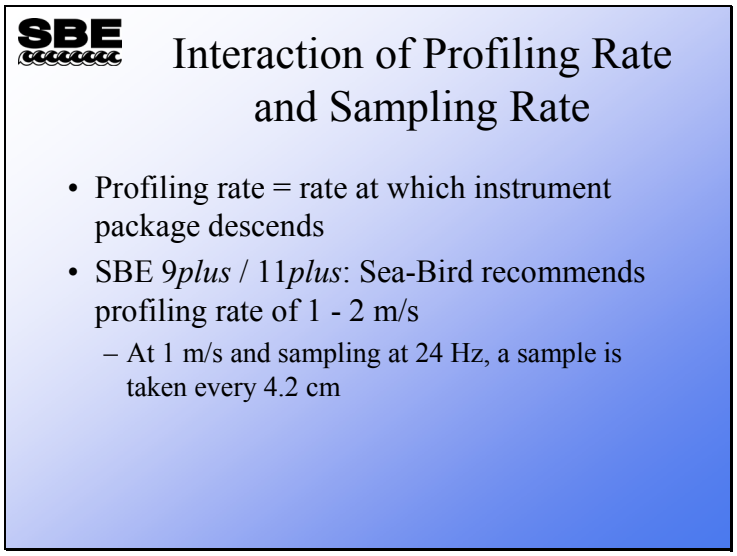
To induce a change in the oxygen sensor reading, oxygen in the environment must diffuse through a water boundary layer to the membrane surface. Next it must diffuse through the Teflon membrane that covers the electrode and into the electrolyte above the electrode. There a chemical reaction takes place at the electrode surface. The rates of these processes are temperature dependent. Thus the response of the sensor to a step change in its environment is temperature dependent. The plot above shows the changes in Tau for a typical sensor. Nominally, Tau at 20° C is 2 seconds, but varies with the age and condition of the sensor and membrane.

CTD Sampling Rates



Sea-Bird offers CTDs with sampling rates shown above. The SBE 9*plus*, with the fastest sampling rate, produces the most detailed data. The other instruments are less capable but offer lower price, less complex deployment equipment, and a more compact instrument package. Not all applications require or benefit from the sampling rates achievable with the SBE 9*plus*.

Sampling Rate and Profiling Rate

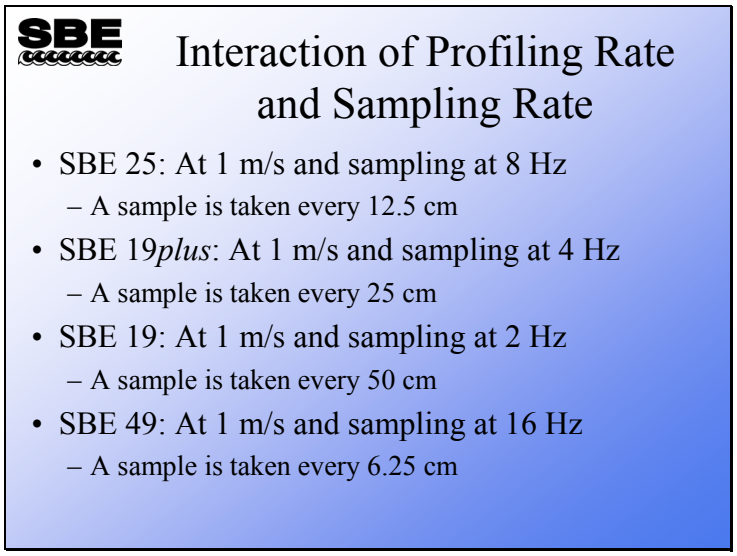


The CTD samples at a fixed rate and the instrument package is lowered through the ocean at a fixed rate. Consider the SBE 9*plus*, sampling at 24 Hz and falling through the ocean at 1 m/s. We would be taking a sample every 4.2 cm.

$$100 \text{ cm sec}^{-1} / 24 \text{ sec}^{-1} = 4.2 \text{ cm}$$

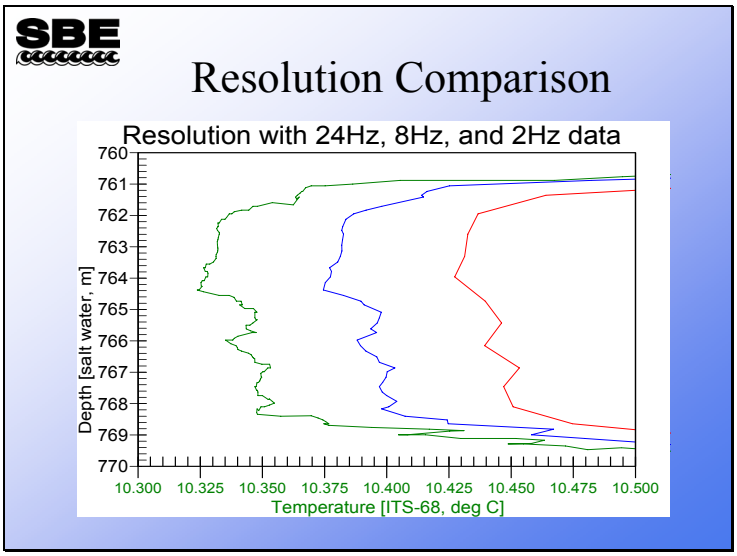
Now consider reality. The CTD samples at 24 Hz and the instrument package falls through the ocean at a nominal 1 m/s. However, the ship heaves, alternately slowing and lifting the instrument package or dropping and accelerating the instrument package. This situation is not well enough constrained to assign an exact length scale to our measurement. We will investigate this problem further in the advanced data processing portion of the course.

Sampling Rate and Profiling Rate (*continued*)



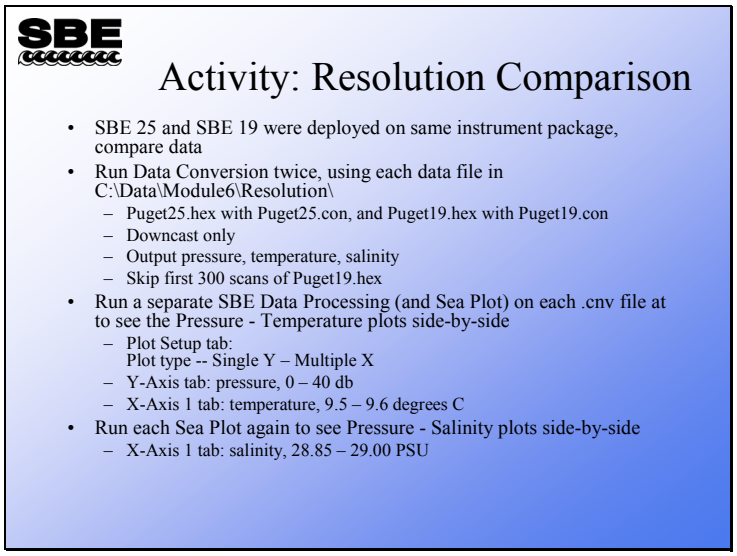
As discussed earlier, the lower sample rates of the SBE 19, 19*plus*, 25, and 49 instruments translates into a coarser resolution than that calculated in the SBE 9*plus* example. The following page illustrates the impact that sample rate has on resolution.

CTD Resolution Comparison



The left-most plot is data collected at 24 Hz with a nominal 1 meter/second lowering speed. The middle plot is the same data set decimated to 8 Hz to represent the resolution of the SBE 25. The right-most plot is the 24 Hz data set decimated to 2 Hz, which is representative of the resolution that would be seen with an SBE 19. The obvious conclusion is that a faster sampling rate yields higher resolution of temperature structure in the ocean temperature profile.

Activity

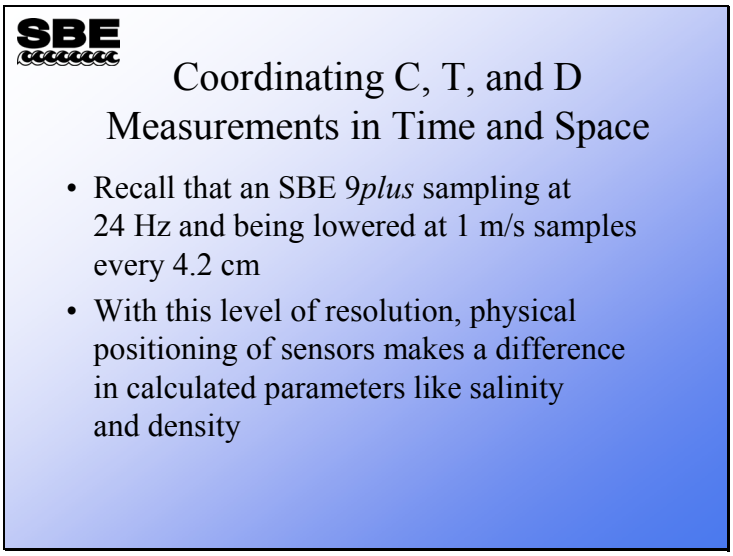


This activity requires some clever use of the processing software. First, use SBE Data Processing's *Data Conversion* module to convert downcast data from C:\Data\Module6\Resolution\Puget25.hex. Then run *Data Conversion* to convert downcast data from C:\Data\Module6\Resolution\Puget19.hex, but skip the first 300 scans; these are invalid data acquired during the instrument package soak.

Next, run SBE Data Processing's *Sea Plot* module, and create a plot for Temperature vs Pressure of Puget25.cnv, as described in the slide above. Adjust the resulting plot so it fills half your screen. Now, open another copy of SBE Data Processing and run *Sea Plot* again; make a plot of Puget19.cnv with the same plotting parameters and adjust it to fill the other half of your screen. How do the plots compare?

Now try Salinity vs Pressure.

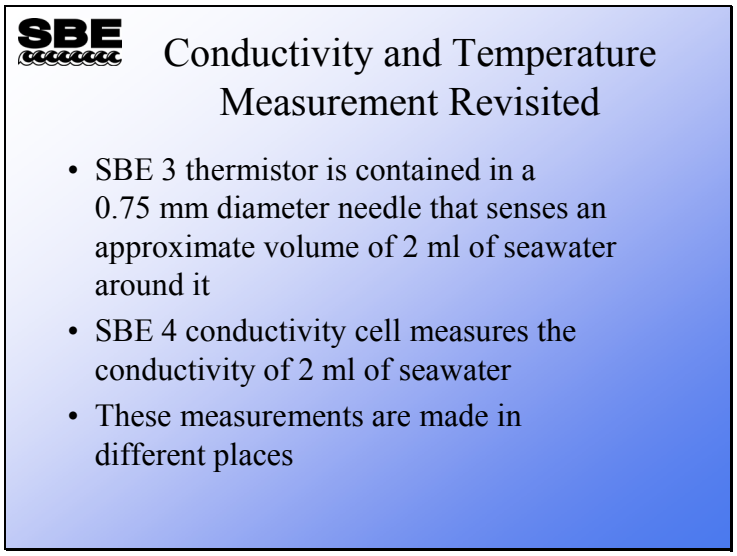
Coordinating Measurements



Salinity is a function of conductivity, temperature, and pressure. The mathematical relationship that defines salinity in these terms was established in 1978 by a group of scientists working with the international scientific organization UNESCO.

Salinity must be calculated from conductivity, temperature, and pressure measurements made on the same water parcel.

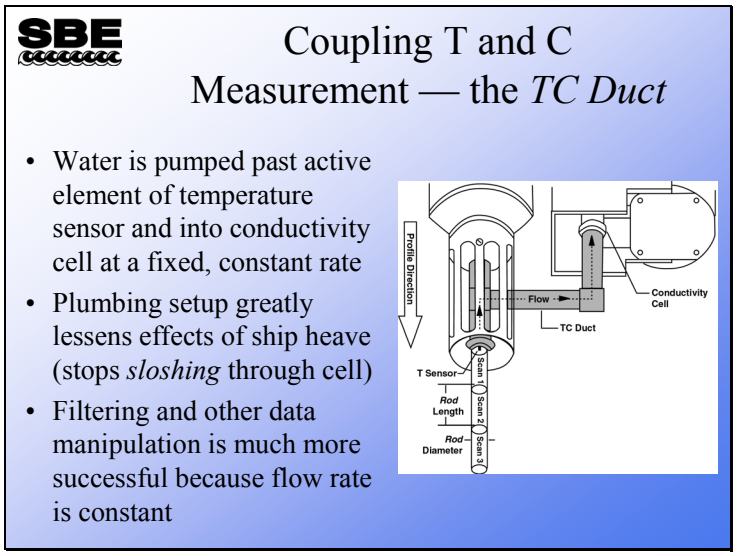
Coordinating Measurements (*continued*)



The active part of the thermometer is found at the end of the slender needle. The volume of water measured by the end of the needle is approximately 2 ml.

Recall that the conductivity cell is a glass tube containing platinum electrodes; conductivity is measured on the volume of water that the cell contains, approximately 2 ml.

Coordinating Measurements (*continued*)

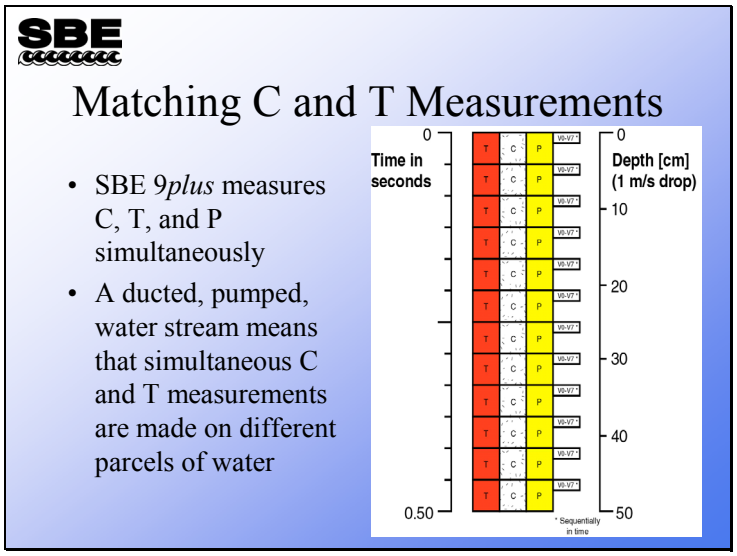


To ensure that the temperature and conductivity measurements are made on a constrained water sample, they are plumbed together and the *T-C pair* has water drawn through them with a pump that moves water at a consistent, known speed.

One way to visualize this is as a *rod* of water that moves into the duct and flows past the thermometer and into the conductivity cell. The diagram above shows the approximate size of the water parcel that constitutes a sample.

Because the water sample is pumped through the duct and conductivity cell, it is not subject to accelerations (sloshing) due to ship heave. This technique of constraining the sample as it is measured greatly improves the quality of the measurement and facilitates data manipulation.

Coordinating Measurements (*continued*)

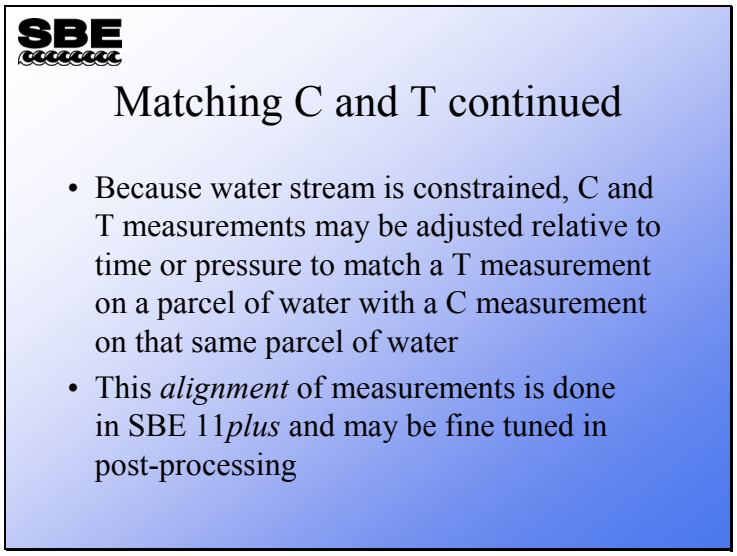


The SBE 9*plus* acquisition architecture measures temperature, conductivity, and pressure simultaneously. Careful examination of the plumbing of the TC duct shows that a water parcel first encounters the SBE 3 thermistor and then transits into the conductivity cell.

For the most accurate estimate of salinity and density, the data stream must be manipulated, moving temperature and conductivity relative to pressure to match the measurements on a parcel of water.

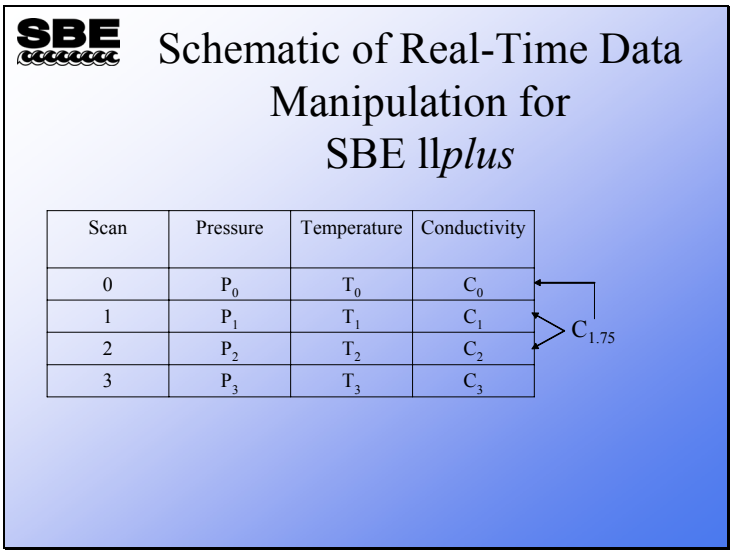
Because the 9*plus* measures T, C, and P simultaneously, and owing to the distance that the sample travels in the plumbing of the TC duct and the conductivity cell, the water that the T sample is taken from at time 0 is actually the same water that the C sample is taken from during time 2.

Coordinating Measurements (*continued*)



The adjustment of samples in the data stream is taken care of in the SBE 11*plus* deck unit and is termed *sample alignment*. Although we have been discussing the advancement in terms of an integer number of scans, careful calculation of flow rates, plumbing distances, and sample rates yields a nominal adjustment of 1.75 data scans. Because the conductivity cell is plumbed after the temperature, the conductivity channel must be advanced relative to the pressure and temperature measurements. The next slide illustrates this with an example.

Coordinating Measurements: Aligning Data

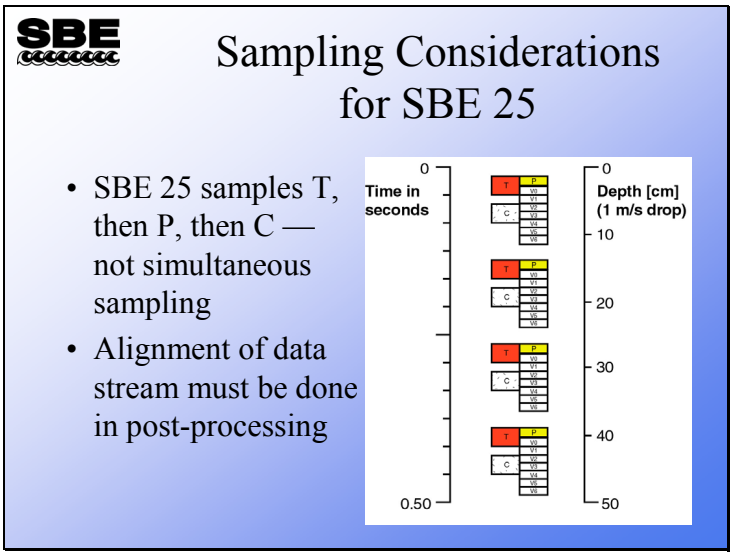


For example, a value for conductivity at 1.75 scans, $C_{1.75,}$ is calculated by interpolating between the values for $C_1$and C_2. C_0 is set to equal $C_{1.75.}$ Then C_1 is set to equal the value obtained from interpolation between C_2 and C_3. This process continues to the end. The 11*plus* can perform this advancement on each of its data channels, with different advancements for each channel. The amount to advance a channel is entered in seconds. Recall that the 9*plus* collects scans at 24 Hz, which equals 0.042 seconds/scan; therefore, a 1.75-scan advancement equals 0.073 seconds.

You might want to enter advancement values for dissolved oxygen sensors or fluorometers as well as for conductivity.

The 1.75-scan advancement is a nominal value; changes in flow rate caused by plumbing changes will necessitate changes in advancement. Similarly, you should consider any advancement that the 11*plus* makes to your other sensors a nominal value and make your final decision based on observing the data.

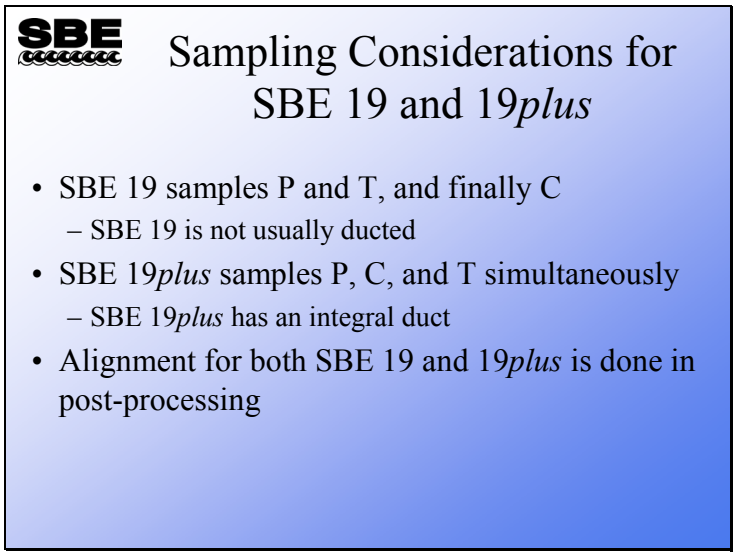
Coordinating Measurements: SBE 25



The SBE 25 has a different sampling order. The alignment of T and C must be done in post-processing, regardless of whether the SBE 25 is used for internally recording data or as a real-time instrument with a deck unit. As an internally recording instrument, the SBE 25 has the capability of averaging samples to increase the memory endurance. Averaging degrades the resolution of the instrument and makes the alignment of T and C less effective.

As the diagram shows, T and P are measured simultaneously, with C following. The SBE 25 has the same pump and TC duct as the 9*plus*, yielding the same transit time for water moving past the thermometer and through the cell. A good nominal advance for conductivity is the same as for the 9*plus*, 0.073 seconds.

Coordinating Measurements: SBE 19 and 19*plus*

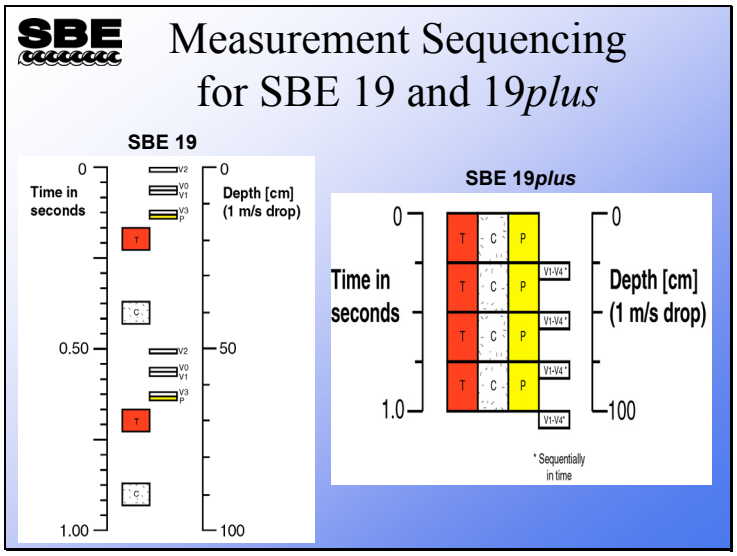


The SBE 19 has a different sampling protocol than the SBE 25 and the 9*plus*. The 19 uses the same signal condition circuit, an oscillator, to sample both T and C. A relay switches the oscillator between the thermistor and the conductivity cell. Further, to improve circuit stability, reference resistors are switched into the oscillator every 120 samples.

The SBE 19*plus* samples T, C, and P simultaneously. This is an improved protocol over the 19.

Like for the SBE 25, the alignment of T and C must be done in post-processing, regardless of whether the SBE 19 or 19*plus* is used for internally recording data or as a real-time instrument with a deck unit.

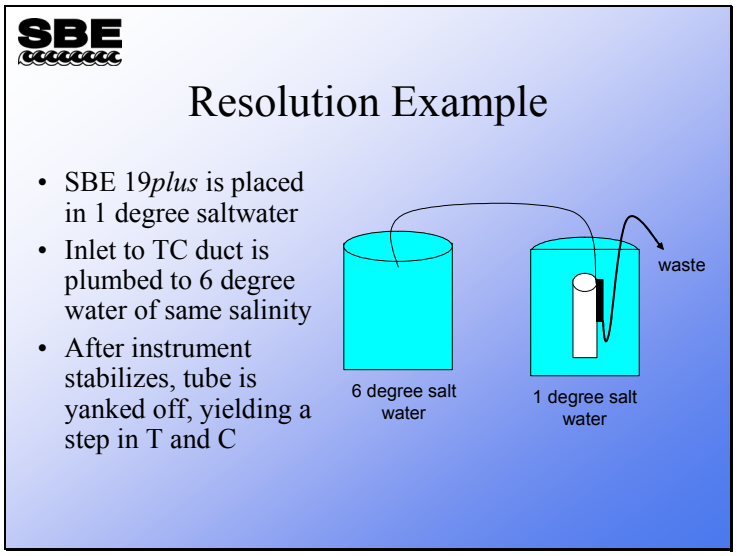
Coordinating Measurements: SBE 19 and 19*plus* (*continued*)



As was mentioned on the previous page, the SBE 19 samples P, then T, and finally C, at a sampling rate of 2 Hz. Because T and C use the same oscillator, there is separation in the measurements to allow time for the oscillator to settle into the new frequency after it has been switched. Alignment of T and C is done in post-processing and, as mentioned earlier, averaging of scans to improve memory endurance tends to degrade the instrument's resolution and make alignment less effective.

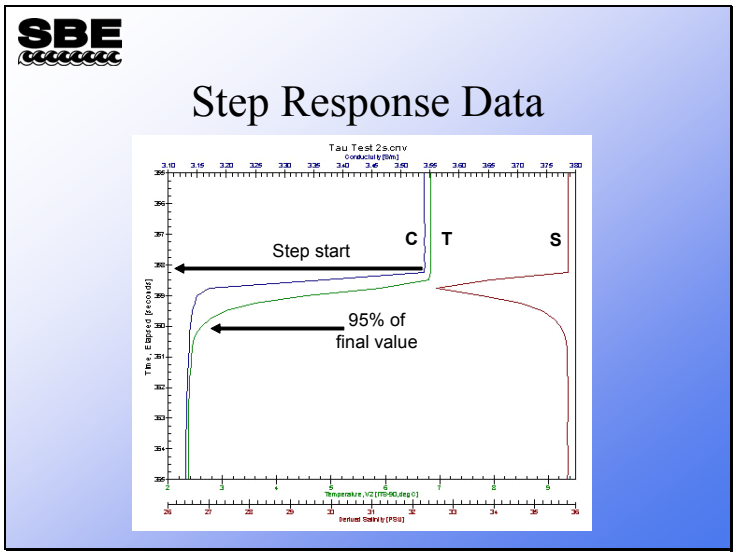
The SBE 19*plus* offers simultaneous sampling of P, T, and C, similar to the SBE 9*plus*. It has a sampling rate of 4 Hz. This sampling schedule is an improvement over the SBE 19 and SBE 25.

Estimating Conductivity and Temperature Resolution



We can conduct an experiment to demonstrate the spatial resolution that is possible with a given set of temperature and conductivity sensors at a specified sampling rate. In our experiment we have a large tank of saltwater at approximately 1 °C. We remove some of the water and allow it to warm to approximately 6 °C. The instrument of interest is placed in the 1 °C water and allowed to equilibrate. The inlet of the temperature and conductivity sensors is plumbed to the warm water tank and water is pumped past the sensors at the normal profiling rate. The warm water is pumped into a waste container so as not to warm the 1°C tank during the test. Data is collected at the highest rate available, and when the system is stable the tubing is yanked off the inlet to the sensors, producing a step change. Our interest is in how well we can resolve rapid changes in the water column in the field. The instrument's step response is an excellent indication of this.

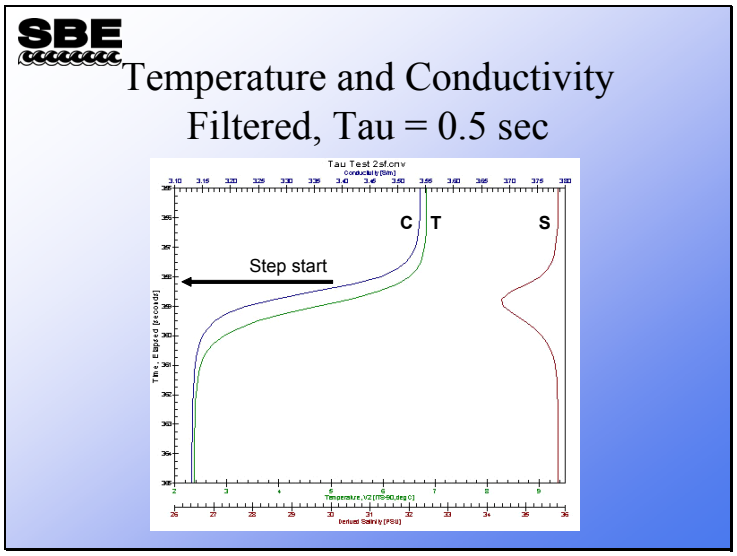
Estimating Conductivity and Temperature Resolution (*continued*)



The above plot shows the results of the experiment. The Y axis is time in seconds; this corresponds to decibars at a lowering rate of 1 meter per second. Note that the temperature trace lags the conductivity trace, because the SBE 19*plus* temperature sensor time constant is approximately 0.5 seconds while the conductivity cell has a time constant of about 0.030 seconds.

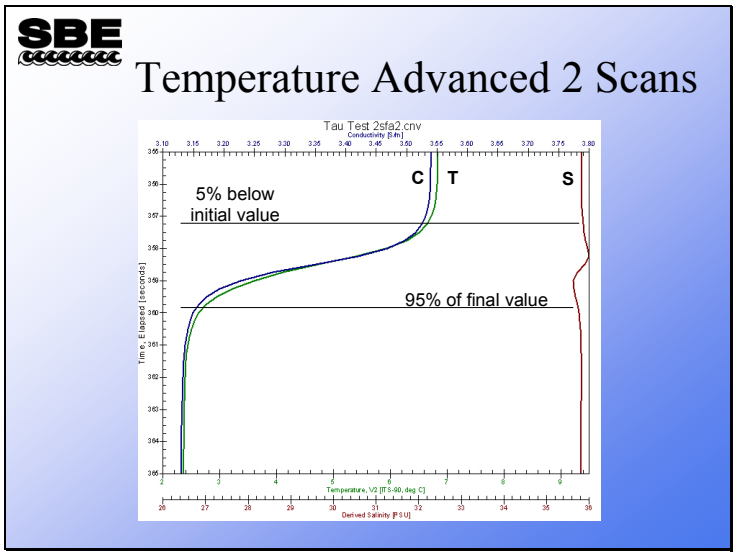
You can observe a large salinity spike produced by the mismatch in the time constants of the temperature and conductivity sensors.

Estimating Conductivity and Temperature Resolution (*continued*)



We can achieve the best salinity response by filtering the temperature and conductivity signals to give them the same time constants. It is accepted practice to filter a data channel forwards and backwards to avoid introducing a phase shift in the data. Because of this, both the leading and the trailing edge of the step response are smoothed. If only conductivity were filtered the smoothed leading edge would not match the temperature channel and a larger salinity spike would result.

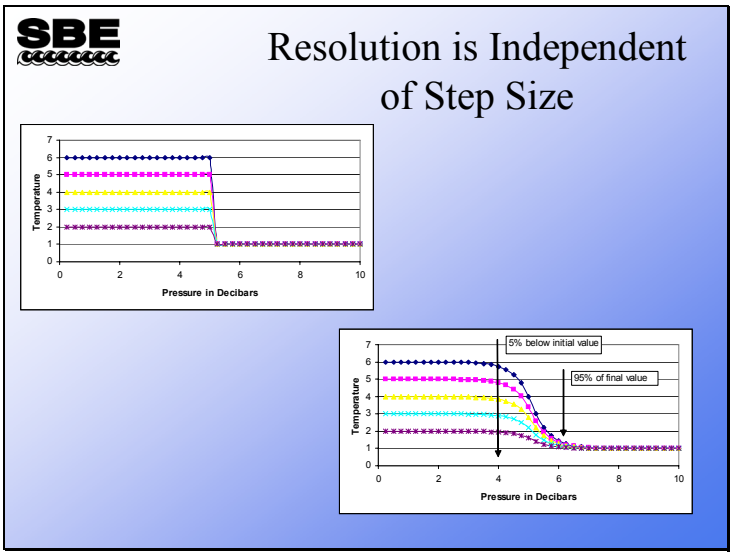
Estimating Conductivity and Temperature Resolution (*continued*)



The next step in the process is to advance temperature relative to time to align the temperature and conductivity channels. Note that the salinity spike is much reduced; if the data were bin averaged on 2 decibar bins, the salinity spike would average out of the data.

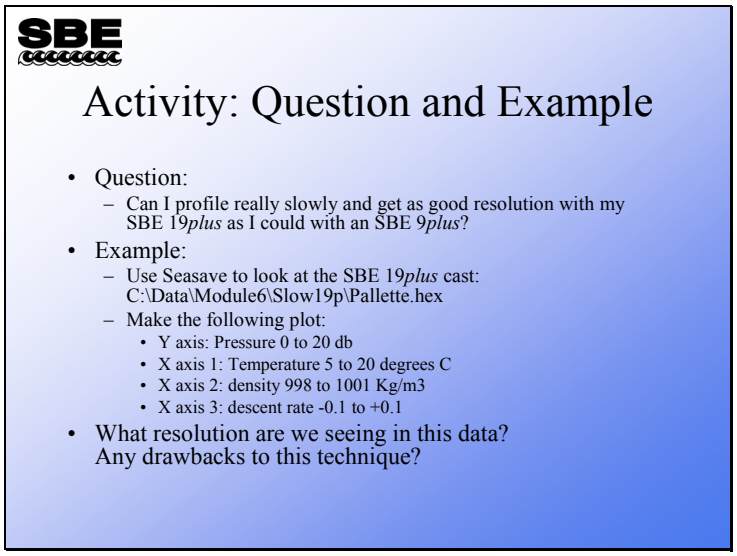
Assuming that a 5% below initial value and 95% of final value criteria are acceptable for the resolution of a step change in temperature and conductivity, the SBE 19*plus* can resolve a step change over approximately a 2.25 second interval (corresponds to a 2.25 decibar interval at 1m/s lowering rate). A slower lowering rate will result in a smaller resolution distance.

Estimating Conductivity and Temperature Resolution (*continued*)



You might think that the resolution of a step change depends on the magnitude of the change. Above are plots of the step response of a filter that closely resembles the temperature response of the SBE 19*plus*. It is obvious that the size of the step does not influence the distance (or time) required to resolve it.

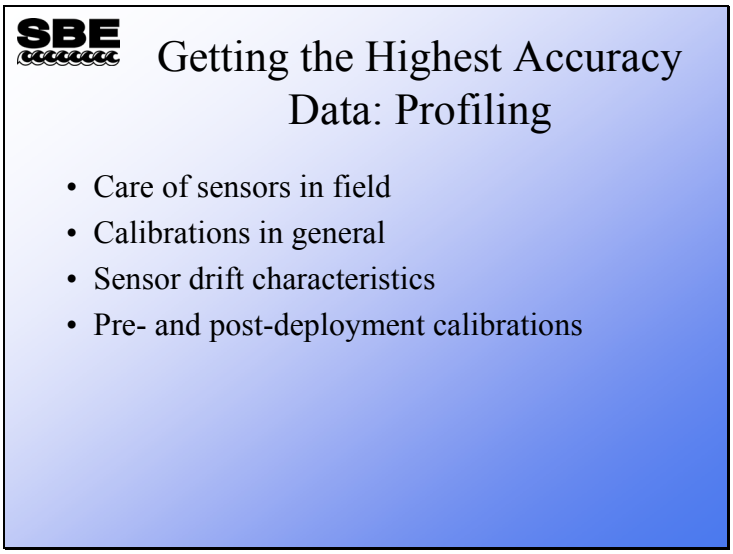
Activity


SBE
Activity: Question and Example
• Question:
– Can I profile really slowly and get as good resolution with my SBE 19plus as I could with an SBE 9plus?
• Example:
– Use Seasave to look at the SBE 19plus cast: C:\Data\Module6\Slow19p\Pallette.hex
– Make the following plot:
• Y axis: Pressure 0 to 20 db
• X axis 1: Temperature 5 to 20 degrees C
• X axis 2: density 998 to 1001 Kg/m3
• X axis 3: descent rate -0.1 to +0.1
• What resolution are we seeing in this data?
Any drawbacks to this technique?

Module 7

Getting the Highest Accuracy Data

Overview

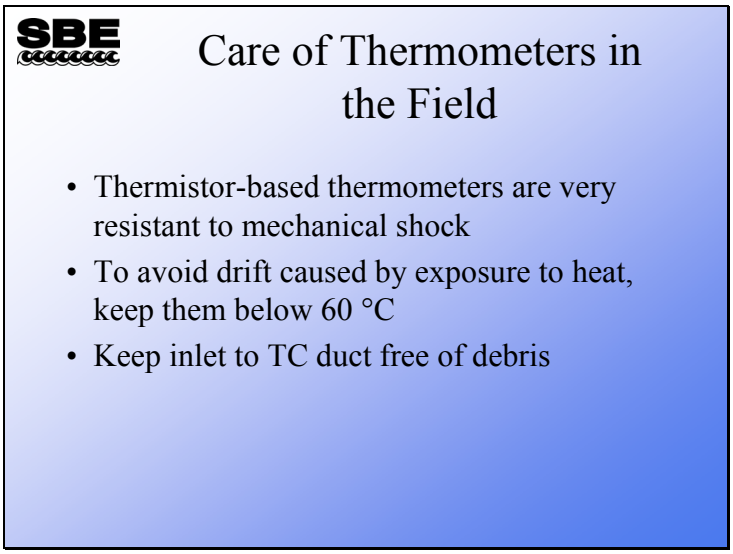


This module covers activities that will improve your data accuracy. Receiving the highest accuracy data from your instrument requires careful handling and attention to calibration. While thermometers are very robust and low maintenance, they still require regular calibration to make sure they are on their historical drift trajectory. A sensor that has a surface that interacts with the seawater, such as conductivity or dissolved oxygen, is another matter. These require careful handling, attention to calibration, and field calibration to assure the highest quality data.

When we finish this module you should be able to:

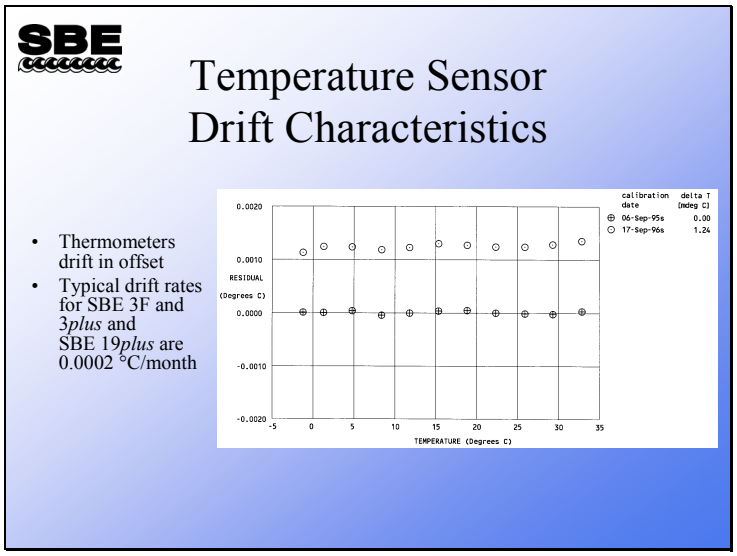
- Minimize handling-induced problems with your sensors.
- Correct your data for calibration drift.

Care of Thermometers in the Field



SBE 3 thermometers are essentially trouble-free. They are mechanically robust and are unaffected by extremes in temperature up to 60 degrees C.

Temperature Sensor Drift Over Time



Temperature sensors tend to drift in offset – that is, the measurements drift in a uniform way over the entire range of measurement. For temperature sensors, the drift direction is dependent on the instrument electronics, and is unique to each temperature sensor. This drift typically continues in the same direction for the entire life of the instrument.

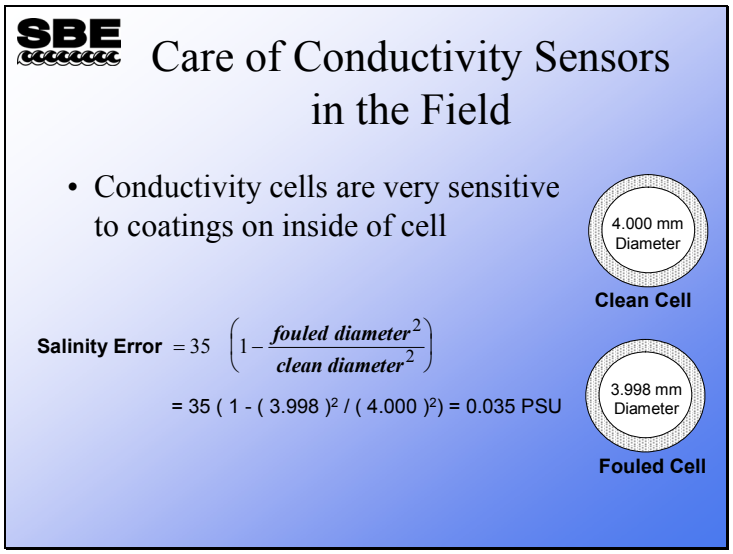
Sea-Bird calculates residual as:

Residual = instrument output – true value

Our calibration certificates always plot the residual on the y axis.

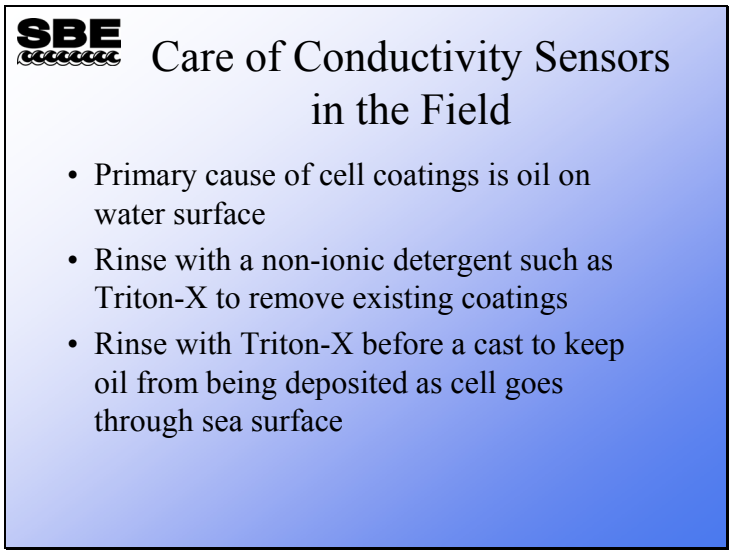
For the plot above, the original calibration in September 1995 shows a residual of 0. A check of the same sensor in September 1996 shows a residual of 1.24 millidegrees. As you can see, the residual is fairly constant across the entire range of the temperature calibration.

Care of Conductivity Sensors in the Field



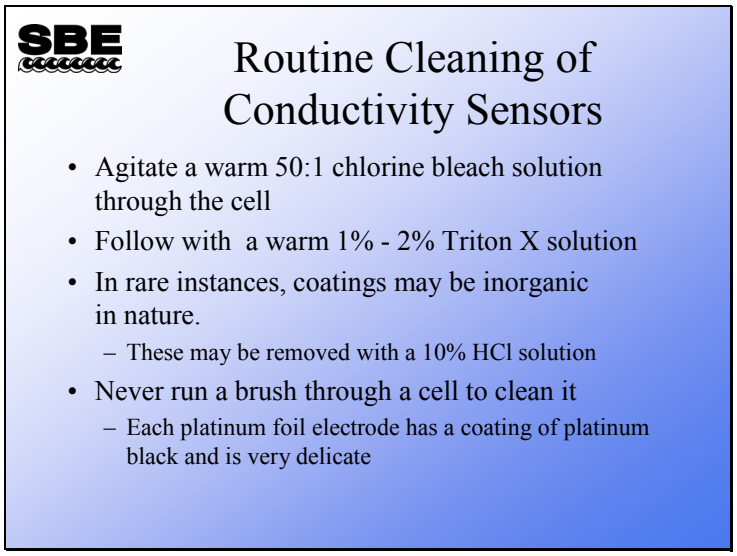
Conductivity sensors have parts that interact with the seawater. There are 3 electrodes that are subject to fouling, and a cell that must maintain constant dimensions. As the slide shows, a 0.001 mm coating will diminish the cell diameter by 0.002 mm, resulting in a salinity error of 0.035 PSU. A film thickness of 0.001 is not uncommon for oils on the sea surface. Another source of fouling is bacterial colonization.

Care of Conductivity Sensors in the Field (*continued*)



Sea-Bird supplies a small amount of Triton-X non-ionic detergent for cleaning conductivity cells. This will remove any oily coating, and an application before deployment will keep films from being deposited as the cell goes through the sea surface. Triton-X is a surfactant. A pre-deployment coating has the added advantage of wetting the electrodes, giving their surface a higher affinity to water.

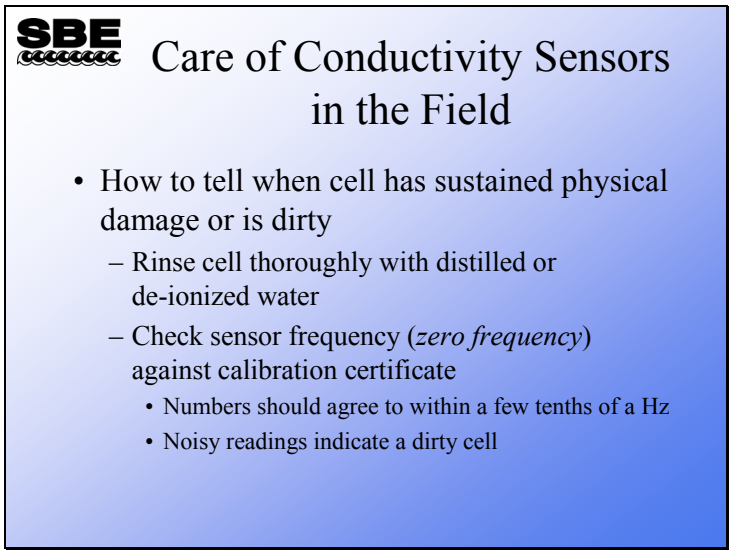
Care of Conductivity Sensors in the Field (*continued*)



The cleaning with dilute bleach and Triton-X may be repeated several times for badly fouled sensors.

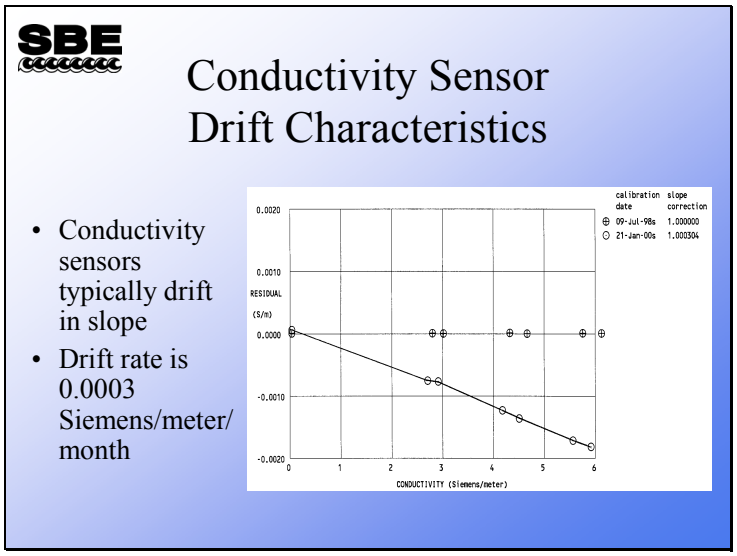
Sea lore has it that in some environments $CaCO_3$ or other inorganic coatings may accrete on the inside of the cell. This is more likely in a moored instrument. A 10% HCl solution will dissolve these. Rather than doing this aggressive cleaning yourself, Sea-Bird recommends that the sensor be returned to the factory for cleaning and inspection.

Care of Conductivity Sensors in the Field (*continued*)



Every conductivity calibration certificate has a frequency output for zero conductivity. This is obtained from a cell thoroughly rinsed in distilled or de-ionized water, with all the water shaken out. This means there are no electrical paths within the cell. A zero frequency that has changed by more that a few 10ths of a Hertz may indicate a cell that is damaged or considerably out of calibration. Noisy readings (± a few 10ths of a Hertz) indicate a dirty cell; we suggest a good rinse with dilute bleach and Triton-X.

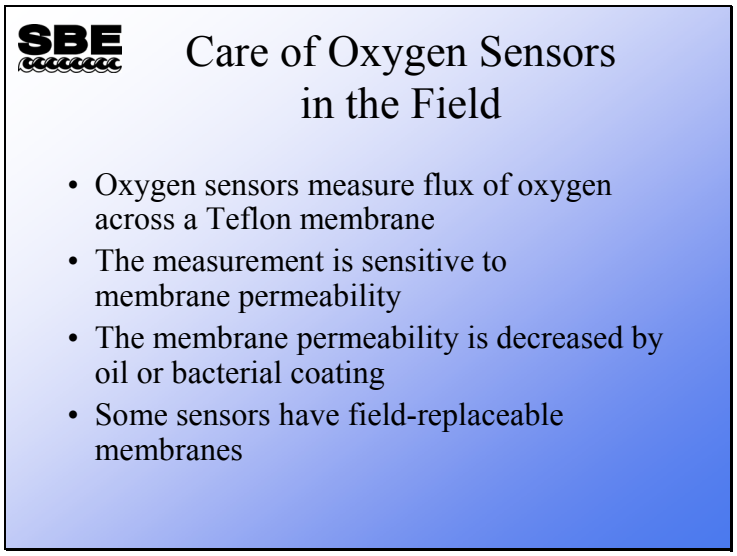
Conductivity Sensor Drift Over Time



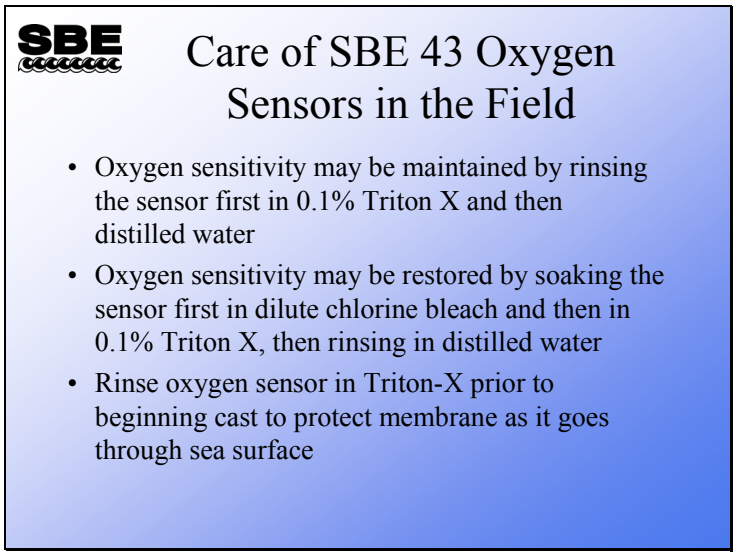
Conductivity sensors usually lose sensitivity as they drift. The drift takes the form of a slope. This is because the conductivity measured by the cell depends on the cell dimensions, which typically change due to fouling.

Note that conductivity cell drift is often episodic rather than linear. This is because fouling events often cause the most significant drift. Perhaps the sensor passes through an oil film when it enters the water, or sits on deck in a warm place full of seawater, growing bacteria on the cell surface.

Care of Oxygen Sensors in the Field



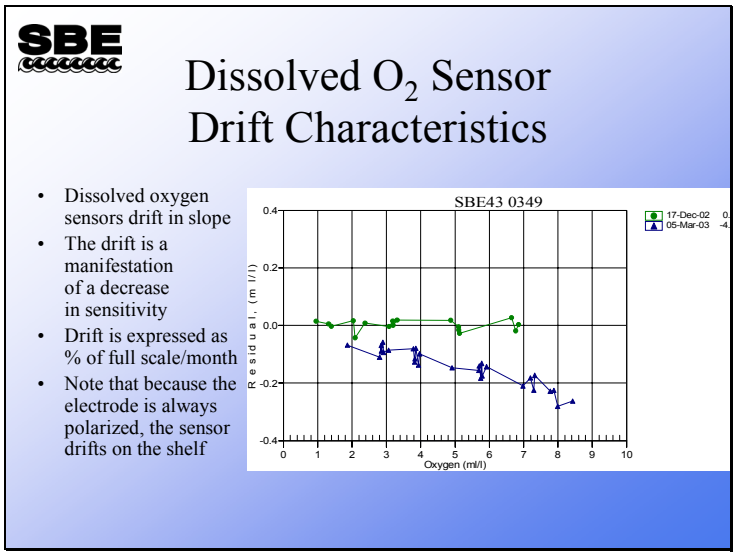
Care of Oxygen Sensors in the Field (*continued*)



In the past, we recommended using Triton X-100 for the combined purpose of degreasing and discouraging biological growth. We recently discovered that prolonged exposure of Triton X-100 to the sensor membrane is harmful and causes the sensor's calibration to drift. Our present recommendation is to continue to use Triton X-100 for degreasing (with a short wash), and to use a short wash with a dilute chlorine bleach solution to reduce biological growth.

- Avoid fouling the oxygen membrane with oil or grease as this directly affects (reduces) the sensor output.
- **Preventive Field Maintenance between Profiles**: After each cast, flush with a 0.1% solution of Triton X-100, using a 60 cc syringe, then rinse thoroughly with fresh water. Between casts, ensure that the membrane remains shaded from direct sunlight and stays cool and humidified.
- **Routine (post-cruise) Cleaning (no visible deposits or marine growths on sensor) -** Follow this two-step procedure:
  1. Soak the sensor for 1 minute in a 50:1 solution of bleach (50 parts de-ionized water to 1 part chlorine bleach). After the soak, drain and flush with warm (not hot) fresh water for 5 minutes.
  2. Soak the sensor for 1 minute in a 1% solution of Triton X-100 warmed to 40 ºC. After the soak, drain and flush with warm (not hot) fresh water for 5 minutes.
- **Cleaning severely fouled sensors (visible deposits or marine growths on sensor)**: Repeat the *Routine Cleaning* procedure up to 5 times.
- **Long-Term Storage (after field use)**: **Do not fill the tubing with water, Triton solution, or Bleach solution.**
  - If there is no danger of freezing, loop tubing from inlet to outlet. Place a small piece of clean sponge, *slightly dampened* with fresh, clean water, in the center of the tubing (not near the membrane).
  - **If there is danger of freezing, shake all excess water out of the plenum and loop tubing from inlet to outlet, leaving the sensor membrane dry.**
  - To minimize drift during storage, connect 1 end of the tubing loop to the plenum, displace the air in the plenum and tubing with Nitrogen gas, and connect the other end of the tubing to the plenum.

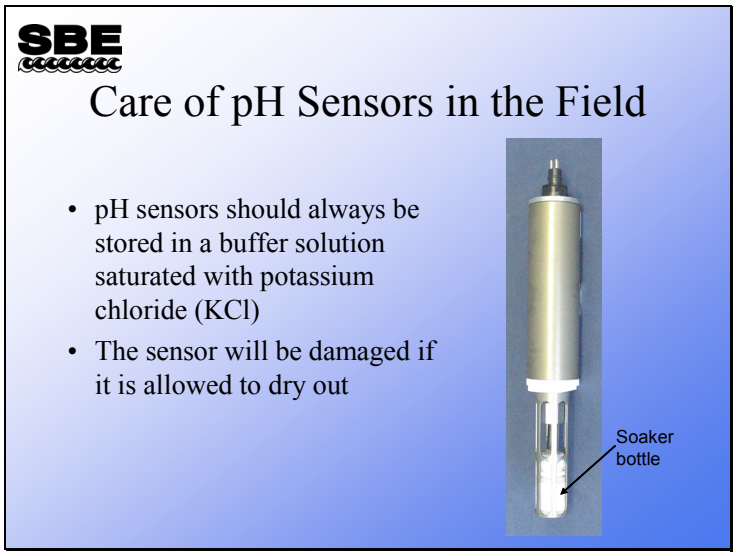
Dissolved Oxygen Sensor Drift Over Time



Dissolved oxygen sensor drift, like conductivity sensor drift, can be episodic in nature. It also has similar causes. The sensor depends on the diffusion of oxygen through a Teflon membrane. Any surface coating that slows the diffusion will affect the sensor sensitivity and its time response.

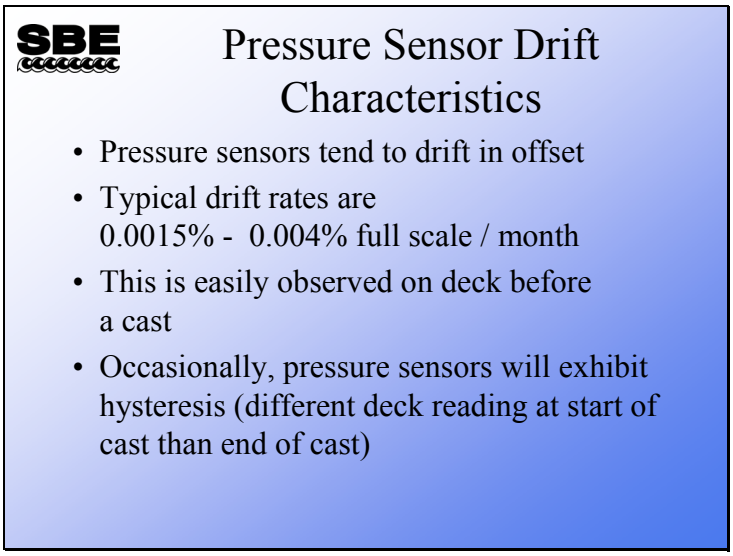
The oxygen sensor drifts in slope. The equation that converts sensor output to dissolved oxygen has a slope term, Soc, which gets larger as the sensitivity of the sensor decreases.

Care of pH Sensors in the Field



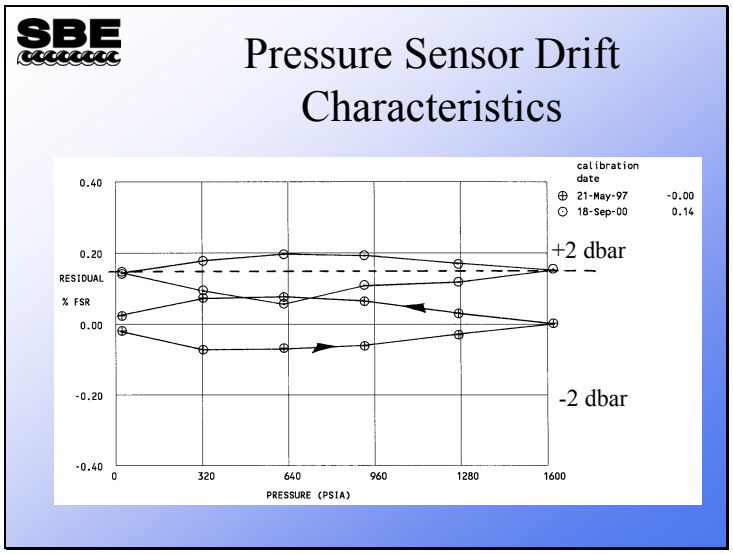
The pH electrode is porous and will dry out if left open to the air. It is always a good practice to keep it in clean, pH 4 buffer solution that has been saturated with potassium chloride (KCl). The electrolyte inside the pH sensor is saturated KCl.

Pressure Sensor Drift Over Time



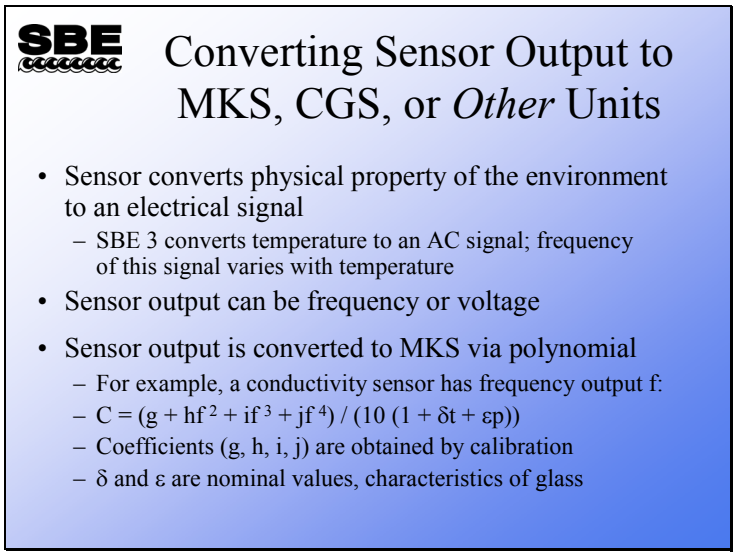
Pressure sensors are usually trouble-free. Drifts are generally in offset. The drift may be read on deck and entered into the coefficient dialog box to make the correction.

Pressure Sensor Drift Characteristics



Here is a plot showing the drift of a 1000 db strain gauge pressure sensor over a 3-year, 4-month period. This sensor meets its drift specification of 0.004% of Full Scale per month (0.00004/month * 1000 db * 40 months = 1.6 db). Also shown is hysteresis; this deviation from a linear behavior is within the sensor's specification for accuracy of 0.1% of Full Scale (0.001 * 1000 db = 1 db).

Converting Sensor Output to Scientific Units



As we have discussed, a sensor has an active element that interacts with the environment, and a conditioning circuit that converts the reaction into a signal that is measurable with normal techniques (e.g., Analog/Digital conversion or counting of a frequency). Having acquired a digital representation of temperature or conductivity, we need to convert this into units useful to scientists and engineers.

The simplest sensor might have a linear response to the environmental parameter of interest. For example, a transmissometer has a simple relationship between voltage output and percent transmittance of the water within its path:

$$\%T = (\text{slope} * \text{voltage output}) + \text{offset}$$

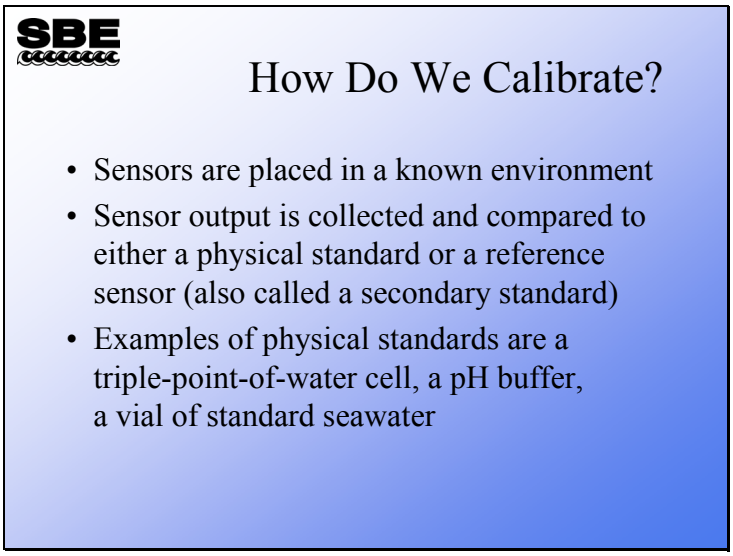
Unfortunately, the output of most sensors in response to environmental parameters is a complex polynomial, often parametric in nature. Consider the equation for conversion from SBE 3 output frequency to temperature. The response is a polynomial because the thermistor responds to changes in temperature in a non-linear fashion:

$$T\,[°C] = [1 / (g + hln(fo/f) + iln^2(fo/f) + jln^3(fo/f))] - 273.15$$

The conductivity sensor's response is a polynomial and parametric, because the sensor has secondary response to temperature and pressure:

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

Converting to Scientific Units: Calibration

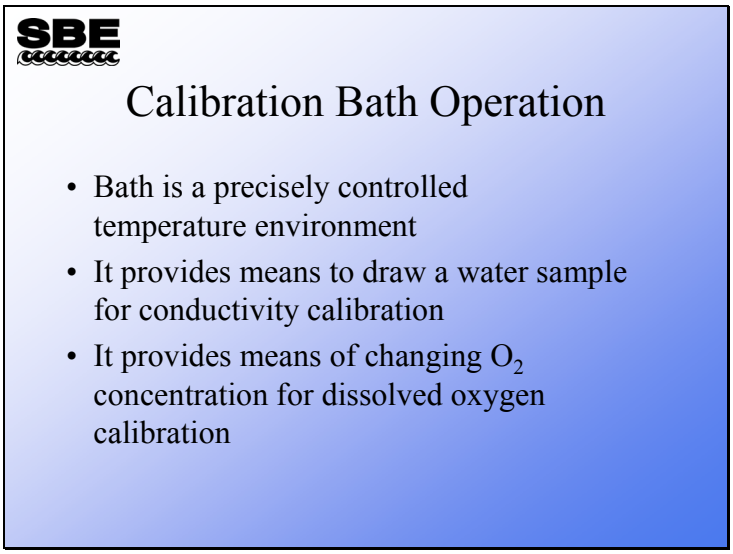


To calibrate a sensor, it is placed in a precisely controlled environment. The output of the sensor is collected at the same time as the environment is measured with a reference sensor. The reference sensor is carefully calibrated and has a well-known history. To gain the careful calibration and history, the reference is calibrated against physical standards such as the triple point of water and the melting point of gallium, or an agreed-upon standard such as IAPSO standard seawater.

Converting to Scientific Units: Calibration (*continued*)

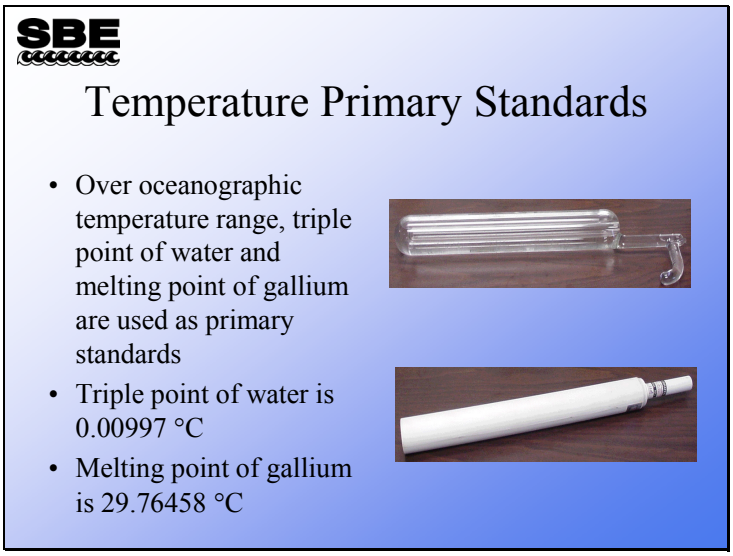
This bath design is common to all of Sea-Bird's calibration activities. The baths are highly insulated and well stirred, and they typically hold temperature to better than 0.0005 °C.

Converting to Scientific Units: Calibration (*continued*)



Baths of this design have been adapted for calibration of all of Sea-Bird's products. The basis is precisely controlled temperature and the ability to draw a water sample for salinity determination. The means to change partial pressures of Oxygen for SBE 43 calibration has been added.

Converting to Scientific Units: Calibration (*continued*)



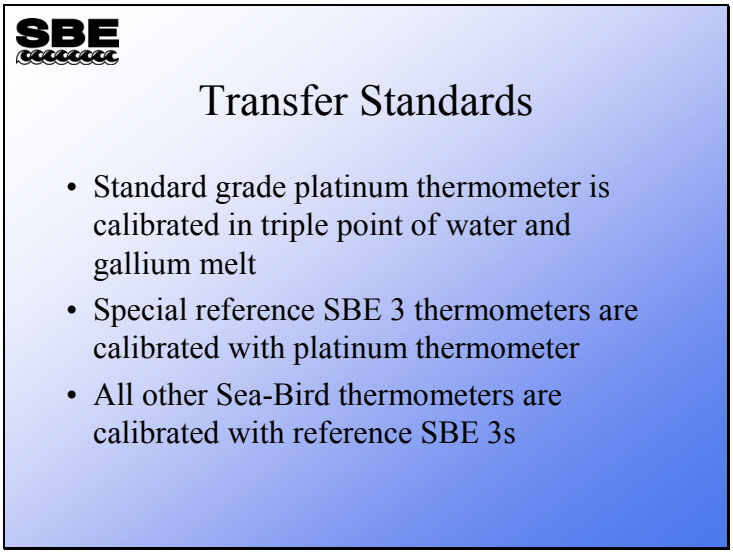
In considering calibration, one runs into the problem of knowing exactly what is the temperature of a particular object. If we only had thermometers to rely on, how do you know which one is right? Instead, we use physical standards. The Celsius temperature scale decrees that water freezes at 0 °C and boils at 100 °C; however, the freezing point and boiling point are subject to uncertainties such as atmospheric pressure. So, instead of the freezing and boiling point, we use two other points:

- The triple point - the temperature at which water exists as a liquid, a vapor, and a solid. The triple point of water is measured in a specially constructed cell that contains no air, only H_20, and occurs at 0.00997 °C.
- The melting point of extremely pure gallium, 29.76458 °C. This pins down the other end of the oceanographic scale.

We calibrate platinum reference thermometers at these points and then calibrate reference SBE 3 sensors with the platinum thermometers. This allows us to trace the temperature measurement used to calibrate all other thermometers back to the physical standards.

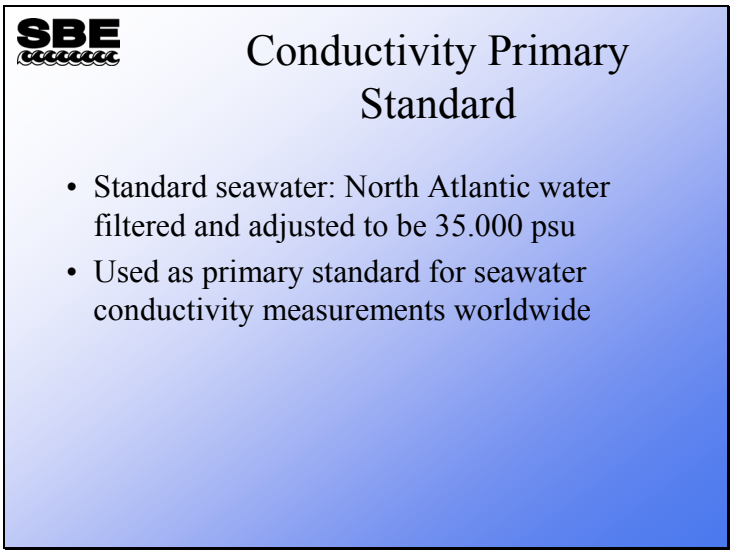
Fixed point cells are called this because when they are in the proper condition their temperature is fixed by the physics of the materials they are constructed of to be a single temperature. The triple point cells are maintained in a water bath very near their natural temperature. This allows them to last a long time. The gallium cells are melted slowly in an oven; the temperature where the gallium changes phase from solid to liquid is used as the calibration temperature.

Converting to Scientific Units: Calibration (*continued*)



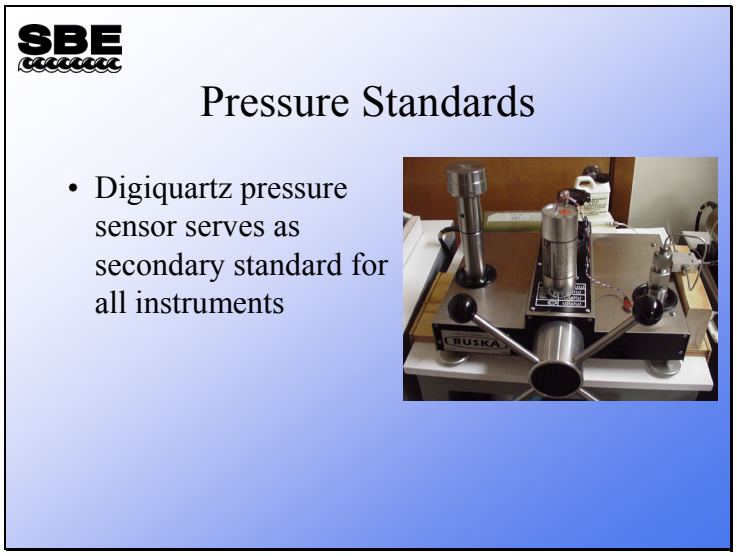
As was previously mentioned, a platinum thermometer is calibrated in the fixed point cells and then used to calibrate the SBE 3 reference thermometers. The platinum thermometer is susceptible to calibration shift due to impact or vibration; because of this it is impractical to use it in routine calibration. The SBE 3s are much more robust. By careful selection of the SBE 3 and the accumulation of a drift history, very accurate calibrations can be accomplished.

Converting to Scientific Units: Calibration (*continued*)



Unlike temperature, a primary standard for the conductivity of seawater is more difficult to come by. In recognition of this, IAPSO commissions the Ocean Scientific International Corporation to provide *standard seawater*. Ocean Scientific sends small ships out into the North Atlantic with large tanks to collect seawater. The seawater is filtered and adjusted in salinity to be 35.000. It is then sealed in vials or bottles and shipped to laboratories worldwide to be used in standardizing laboratory salinometers. Because everyone uses the same water to standardize their salinometers, we are all synchronized with Ocean Scientific. The standard seawater service has been going on for decades under the auspices of various committees of scientists. It was first produced by a laboratory in Copenhagen and was initially dubbed *Copenhagen water*.

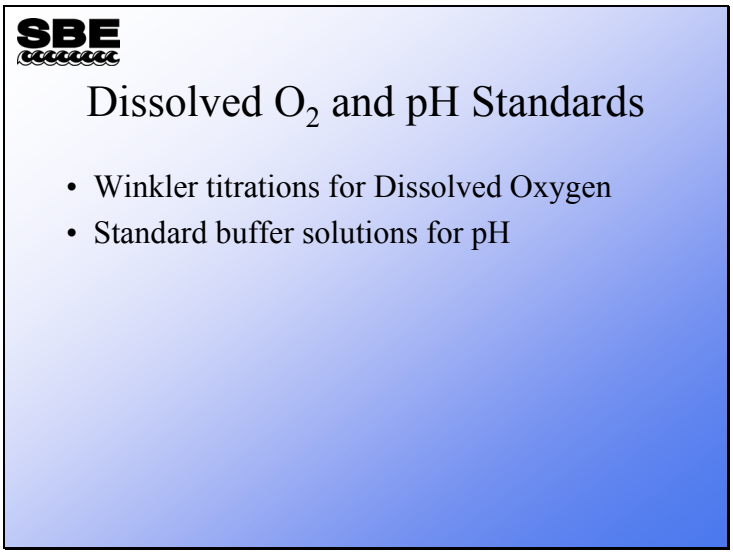
Converting to Scientific Units: Calibration (*continued*)



For instruments that have a strain gauge pressure sensor (Druck, Paine, Ametek, etc.), a complete pressure calibration is performed at Sea-Bird, using our Digiquartz pressure sensor as a secondary standard.

For instruments (SBE 9*plus*, 26*plus*, 53, etc.) that have a Digiquartz pressure sensor, a true calibration of the sensor is performed by the pressure sensor manufacturer. The quality of the Digiquartz is such that an adequate calibration requires a local gravity survey and dead weight tester parts that are certified by the National Institute of Standards and Technology. These requirements, plus the stability of the Digiquartz sensor, make the maintenance of this capability not cost effective for Sea-Bird. However, we do perform a slope and offset check of the pressure sensor in these instruments, using our Digiquartz pressure sensor as a secondary standard.

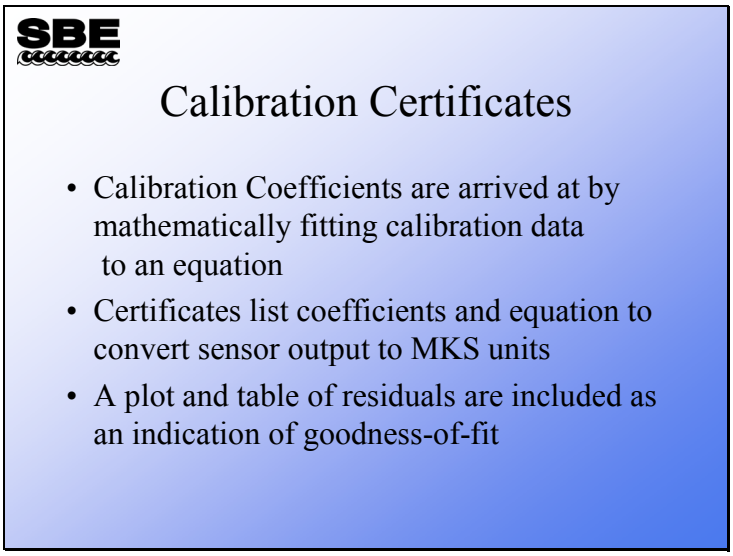
Converting to Scientific Units: Calibration (*continued*)



Dissolved oxygen sensors are calibrated in a bath that is plumbed with oxygen and nitrogen inputs. As gas concentrations are varied during calibration, Winkler samples are collected. These are titrated for dissolved oxygen concentration during the time of the calibration.

pH sensors are calibrated with commercially available buffer solutions.

Converting to Scientific Units: Calibration (*continued*)

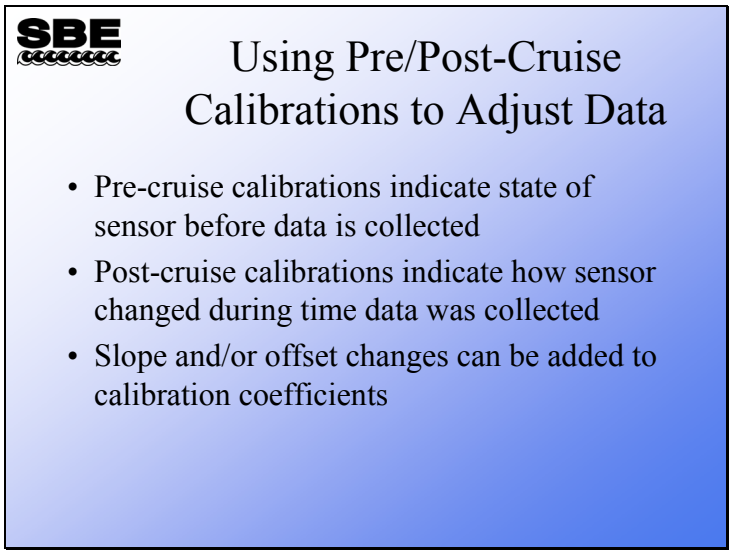


The calibration certificate is a listing of all the information required to convert sensor output to scientific units. There is also a table of calibration data and a plot of residuals that indicates a goodness-of-fit. Residuals are expressed as the difference between the instrument parameter and the bath parameter (the *true* value):

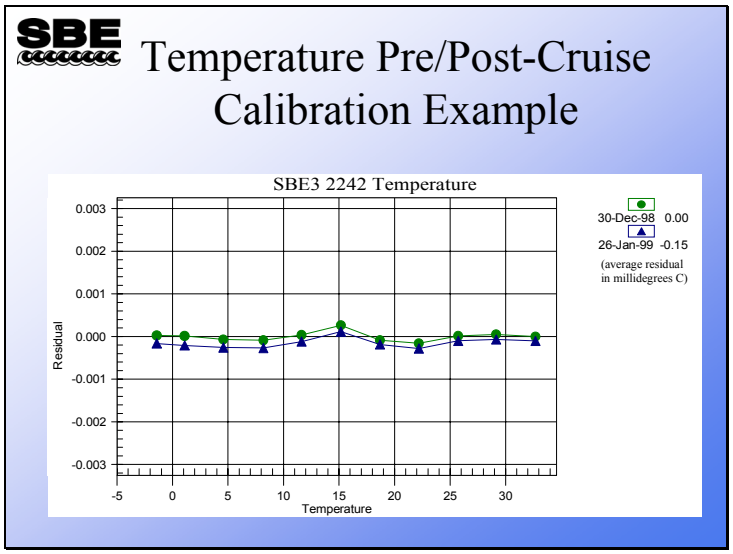
residual = instrument – bath

If the residual is positive, the sensor is reading high of reality; if negative, the sensor is reading low.

Using Calibrations to Improve your Data

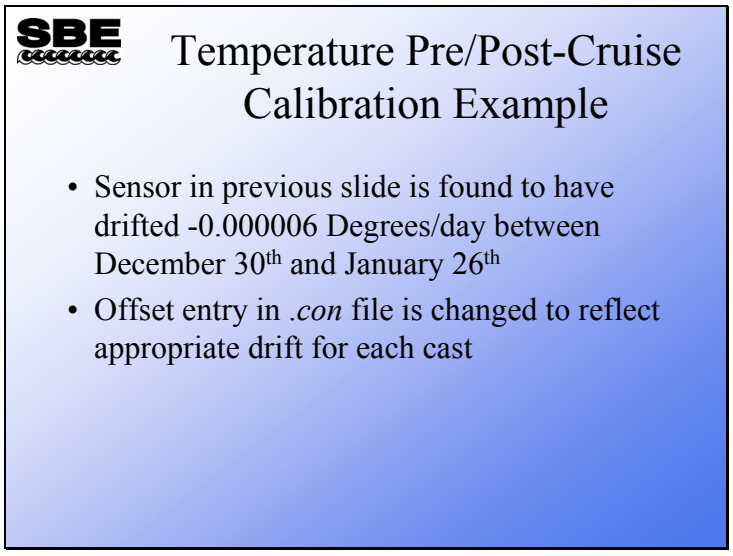


Temperature: Using Calibrations to Improve your Data



Temperature drift is shown to the right of the plot and is expressed as the average residual. The residual is the instrument temperature – the true temperature.

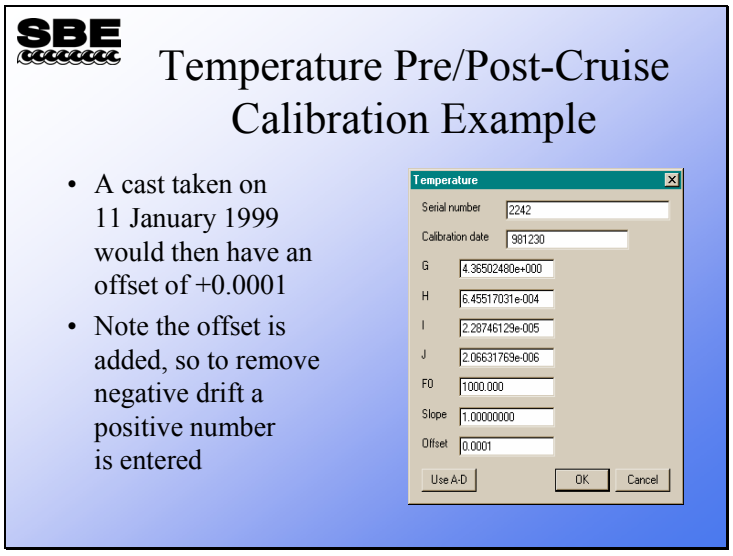
Temperature: Using Calibrations to Improve your Data (*continued*)



The SBE 3 in the previous slide drifted -0.00015 degrees over 27 days, this is -0.000006 degrees per day.

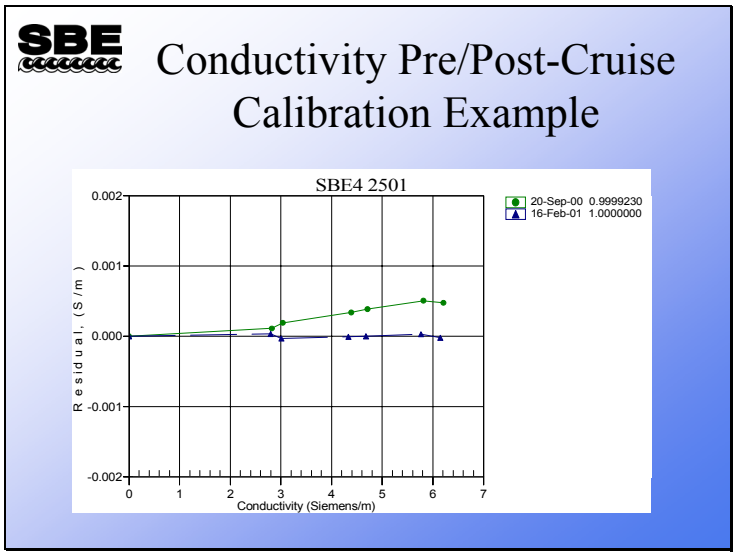
Application Note 31 has a detailed discussion of correcting thermometers with pre-cruise and post-cruise calibrations. Briefly, calibration coefficients are calculated with the post-cruise calibration. Using the post-cruise calibration coefficients and the pre-cruise calibration data, a mean residual over the calibration temperature range is calculated. The residual is the (instrument temperature - bath temperature). The mean residual is divided by the number of days since the pre-cruise calibration. This number is the offset per day. The offset per day is multiplied by the number of days between the pre-cruise calibration and the day the data was collected to get the offset that should be entered into the configuration file.

Temperature: Using Calibrations to Improve your Data (*continued*)



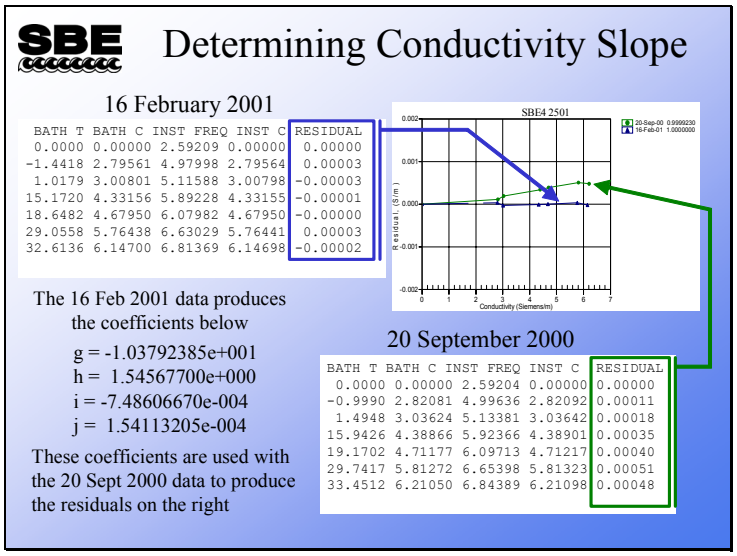
As we noted in the previous slide, the SBE 3 drifted -0.00015 degrees over 27 days, this is -0.000006 degrees per day. Because we are *adding* an offset in the .con file, we need to reverse the sign of the residual before entering it in the .con file (i.e., we need to add an offset of +0.000006 degrees per day). The first day of the cruise is January 11th. Therefore, the offset will be +0.000072 (0.000006 degrees/day x 12 days since the calibration) and will increase +0.000006 every day of the cruise. In the slide above we have rounded the offset to +0.0001.

Conductivity: Using Calibrations to Improve your Data



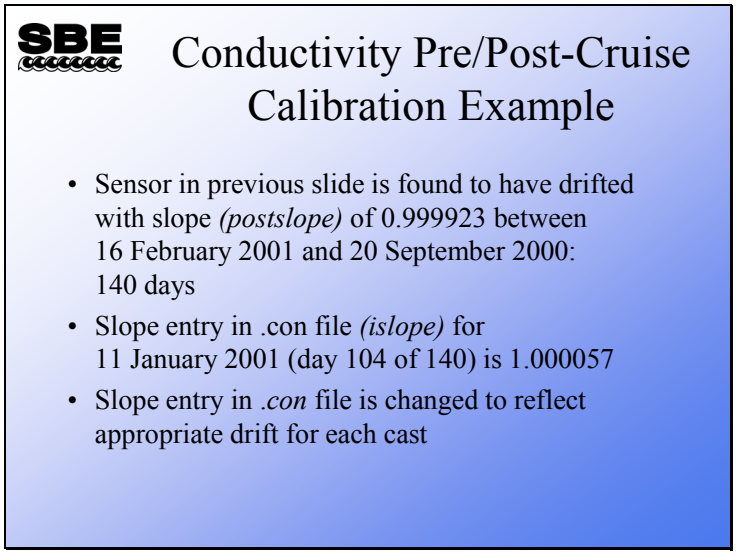
Conductivity sensors usually lose sensitivity as they drift. The drift takes the form of a slope. This is because the conductivity measured by the cell depends on the cell dimensions, which typically change due to fouling.

Conductivity: Using Calibrations to Improve your Data (*continued*)



Conductivity slope is determined by calculating calibration coefficients using data from one calibration date and applying the coefficients to data from another calibration date. Note that the residuals (instrument conductivity – true conductivity) are very small for the 16 February 2001 data. Using the calibrations coefficients calculated from the 16 February 2001 calibration data to calculate instrument conductivities results in the larger residuals seen in the 20 September 2000 data. The results of this show the error that would be incurred from calibration drift.

Conductivity: Using Calibrations to Improve your Data (*continued*)



Refer to Application Note 31 for a detailed discussion of how to apply pre- / post-cruise calibrations to SBE 4 conductivity sensors. Briefly, a calibration is done before and after the cruise. Let alpha be the conductivity that the instrument measured in the pre-cruise calibration, calculated using post-cruise coefficients. Let beta be the true conductivity of the pre-cruise calibrations. Then:

$$postslope = \frac{\sum_{i=1}^{n} \alpha_i \beta_i}{\sum_{i=1}^{n} \alpha_i \alpha_i}$$

Where:
i = 1..n calibration points

The interpolated slope, which is entered in the coefficient dialog box, is:

$$islope = 1 + \left(\frac{b}{n}\right)\left(\frac{1}{postslope} - 1\right)$$

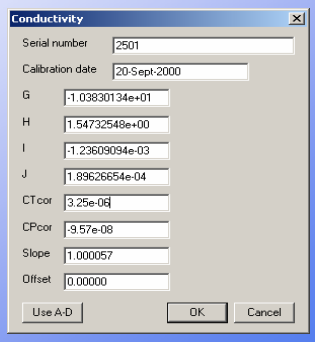
Where:
n = the number of days between pre- and post-cruise calibrations
b = the number of days between pre-cruise calibration and the cast to be corrected
islope = the interpolated slope, which is entered as the slope in the coefficient dialog box
postslope is calculated above

Example: Calculate *islope* for day 104 (11 January 2001) using calibration data from previous slide -
postslope = 0.999923 (at top right of calibration sheet in previous slide)
islope = 1 + (104 / 140) [(1 / 0.999923) – 1] = 1.000057

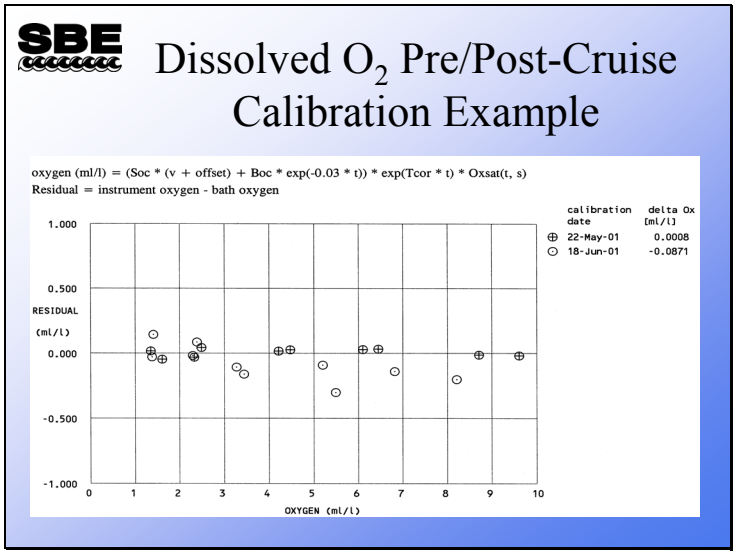
Conductivity: Using Calibrations to Improve your Data (*continued*)

Conductivity Pre/Post-Cruise Calibration Example

- A cast taken on 11 January 2001 would then have slope of 1.000057
- Typical slope corrections may be calculated on weekly interval

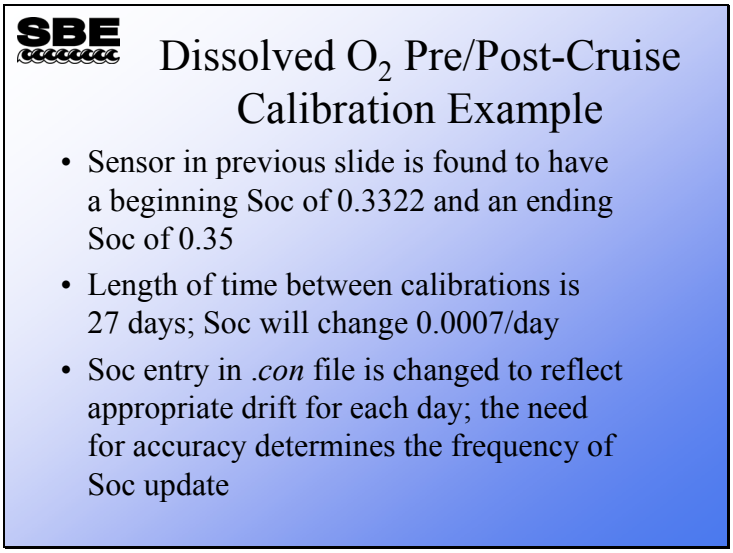


Oxygen: Using Calibrations to Improve your Data



Dissolved oxygen sensors are expected to drift in a similar manner to conductivity. For chemical reasons, they lose sensitivity over time. The equation for calculating oxygen concentration from sensor output has a slope term, Soc, and an offset term, Boc. It is expected that Soc will slowly increase with time, indicating a decrease in sensitivity.

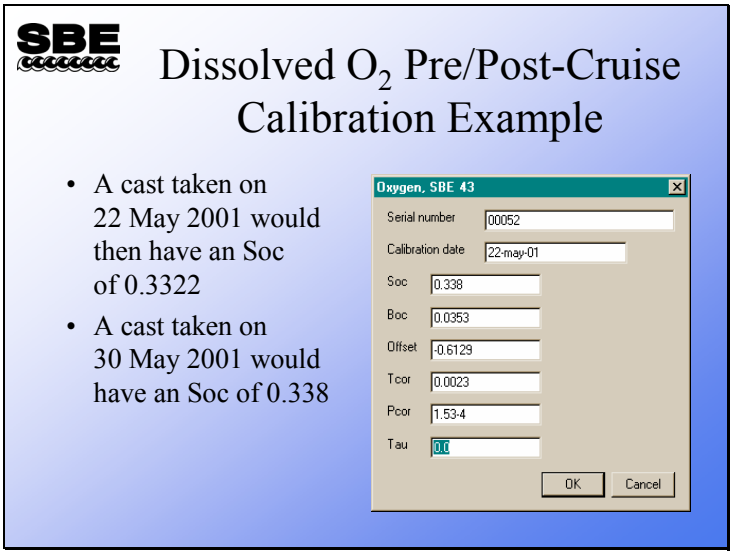
Oxygen: Using Calibrations to Improve your Data (*continued*)



The oxygen sensor calibration sheet provides the value for Soc (that portion of the calibration sheet is not shown in the previous slide).

Note that this strategy of drift correction assumes a uniform, linear change over the time between calibrations. A sensor that is handled carefully, both in deployment and on deck, will exhibit this behavior. However, fouling of the membrane by either oils or bacteria will result in a drift of a more episodic nature.

Oxygen: Using Calibrations to Improve your Data (*continued*)



A word about Tau:

Tau, a coefficient that is part of the Owens and Millard equation, relates oxygen sensor electrode current to dissolved oxygen concentration. Its purpose is to sharpen the oxygen sensor response to time by the inclusion of a derivative term in the equation.

Owens and Millard:

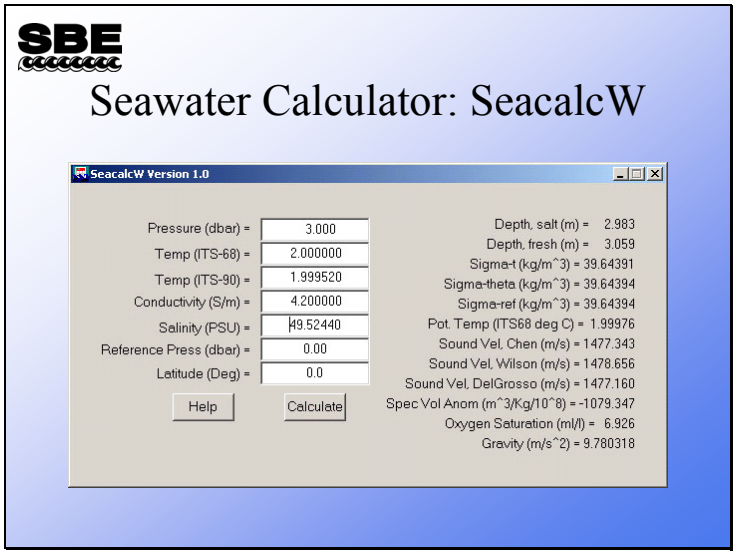
OX = [Soc * (oc + **tau** * doc/dt) + Boc] * OXSAT(T,s)*exp(tcor * [T + wt * (To - T)] + pcor * p)

Where the parts of this equation pertinent to this discussion are:

OX = oxygen concentration
Soc = Slope coefficient
oc = oxygen electrode current
tau = the coefficient we are discussing
doc/dt = the change in electrode current with time

Thus, Tau sharpens the response by adding a term dependent on the change of electrode current with time. This is an imperfect representation of the behavior of the sensor. Because of this, Sea-Bird recommends that Tau be set to zero. It is an entry in the calibration coefficients because it is still present in the equation. If you feel that your sensor could benefit from sharpening, feel free to experiment with Tau.

Calculating Parameters with SeacalcW



SeacalcW is a seawater calculator in SBE Data Processing that computes a number of derived variables from one user-input scan of pressure, temperature, and either conductivity or salinity.

- You can enter temperature in ITS-68 or ITS-90; SeacalcW automatically computes the other value.
- SeacalcW *remembers* whether you last changed conductivity or salinity, and calculates other parameters based on this. For example, if you change conductivity, salinity is recalculated; if you then change temperature, salinity is recalculated again (based on input conductivity and temperature). Conversely, if you change salinity, conductivity is recalculated; if you then change temperature, conductivity is recalculated again (based on input salinity and temperature.
- Reference pressure is used only to compute Sigma-ref.
- Latitude is used only to compute gravity and salt water depth.

Activity: Correct T & C via Pre / Post-Cruise Calibrations

Pressure db	CTD Temperature	CTD Conductivity	Uncorrected CTD Salinity	Corrected CTD Temp	Corrected CTD Cond	Corrected CTD Salinity	Water Bottle Salinity	Corrected CTD Salinity- Water Bottle Salinity
4.9	24.0798	5.236377	35.1885				35.2055	
519	6.6922	3.439905	34.0769				34.0848	
850.6	4.4142	3.276592	34.3667				34.3738	
1000.8	4.003	3.254754	34.4616				34.472	
1202.3	3.5221	3.224822	34.5083				34.5148	
1401	3.039	3.193778	34.5452				34.5503	
1599.6	2.6724	3.171902	34.5692				34.5769	
1800.5	2.3456	3.153669	34.5947				34.601	
1999.1	2.1309	3.1445	34.6131				34.6194	
2200.8	1.9531	3.138118	34.6259				34.6351	
2400.2	1.7884	3.132729	34.6392				34.6463	
2601.2	1.6718	3.131169	34.6486				34.6562	
2798.9	1.5911	3.132338	34.6563				34.6645	
3000	1.5372	3.135717	34.6623					
3200.1	1.4927	3.1397	34.6674				34.676	
3399.7	1.4739	3.145626	34.6708				34.6789	
3600.3	1.4587	3.151747	34.6737				34.6829	
3800.4	1.4465	3.157985	34.6763				34.6846	
4001.5	1.4537	3.165678	34.6772				34.6853	
4201.2	1.4608	3.173241	34.6785				34.689	
4401.9	1.4766	3.181421	34.6790				34.6871	
4500.7	1.4868	3.185577	34.6788				34.6883	
4600.8	1.4969	3.189761	34.6789				34.6883	
4809.4	1.5119	3.19792	34.6795				34.6884	

Note: Cruise date is 15 December 1999, Julian day 348.

(dates from calibration sheets)	**Temperature**	**Conductivity**
Pre-cruise calibration	23 November 1999, Julian day 326	17 June 1999, Julian day 167
Post-cruise calibration	28 December 1999, Julian day 361	30 December 1999, Julian day 363

Use the calibration data from the C and T calibration sheets on the following pages to answer these questions and fill in a few rows of the table:

1. Calculate a temperature offset for the cruise; apply the offset to the temperature data.
2. Calculate a conductivity slope for the cruise; apply the slope to the conductivity data.
3. Calculate corrected CTD salinity with SeacalcW. Compare the corrected CTD salinity to the salinity measured from the water bottle samples.

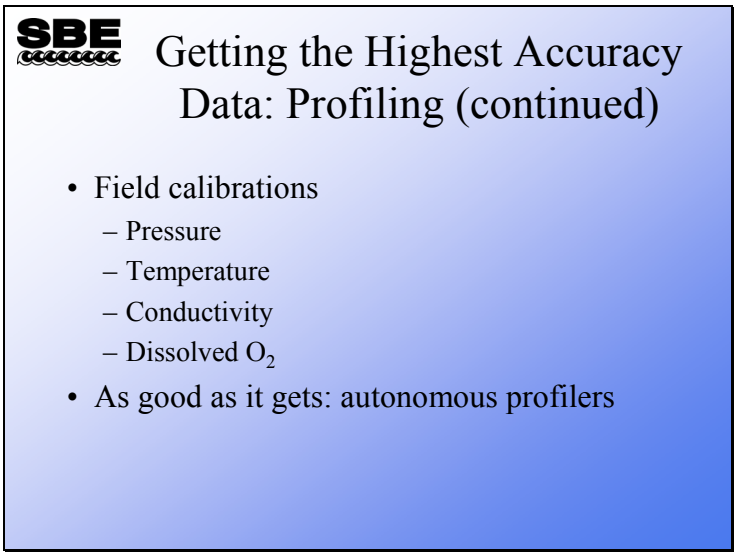
Corrected T and C using Pre- / Post-Cruise Calibrations

Pressure db	CTD Temperature	CTD Conductivity	Uncorrected CTD Salinity	Corrected CTD Temp	Corrected CTD Cond	Corrected CTD Salinity	Water Bottle Salinity	Corrected CTD Salinity- Water Bottle Salinity
4.9	24.0798	5.236377	35.1885	24.0798	5.237190	35.1947	35.2055	-0.0108
519	6.6922	3.439905	34.0769	6.6922	3.440439	34.0828	34.0848	-0.0020
850.6	4.4142	3.276592	34.3667	4.4142	3.277101	34.3726	34.3738	-0.0012
1000.8	4.003	3.254754	34.4616	4.003	3.255259	34.4676	34.472	-0.0044
1202.3	3.5221	3.224822	34.5083	3.5221	3.225323	34.5143	34.5148	-0.0005
1401	3.039	3.193778	34.5452	3.039	3.194274	34.5511	34.5503	0.0008
1599.6	2.6724	3.171902	34.5692	2.6724	3.172395	34.5753	34.5769	-0.0016
1800.5	2.3456	3.153669	34.5947	2.3456	3.154159	34.6006	34.601	-0.0004
1999.1	2.1309	3.1445	34.6131	2.1309	3.144988	34.6191	34.6194	-0.0003
2200.8	1.9531	3.138118	34.6259	1.9531	3.138605	34.6319	34.6351	-0.0032
2400.2	1.7884	3.132729	34.6392	1.7884	3.133216	34.6452	34.6463	-0.0011
2601.2	1.6718	3.131169	34.6486	1.6718	3.131655	34.6547	34.6562	-0.0015
2798.9	1.5911	3.132338	34.6563	1.5911	3.132824	34.6623	34.6645	-0.0022
3000	1.5372	3.135717	34.6623	1.5372	3.136204	34.6682		
3200.1	1.4927	3.1397	34.6674	1.4927	3.140188	34.6735	34.676	-0.0025
3399.7	1.4739	3.145626	34.6708	1.4739	3.146115	34.6768	34.6789	-0.0021
3600.3	1.4587	3.151747	34.6737	1.4587	3.152236	34.6796	34.6829	-0.0033
3800.4	1.4465	3.157985	34.6763	1.4465	3.158475	34.6823	34.6846	-0.0023
4001.5	1.4537	3.165678	34.6772	1.4537	3.166170	34.6832	34.6853	-0.0021
4201.2	1.4608	3.173241	34.6785	1.4608	3.173734	34.6845	34.689	-0.0045
4401.9	1.4766	3.181421	34.6790	1.4766	3.181915	34.6851	34.6871	-0.0020
4500.7	1.4868	3.185577	34.6788	1.4868	3.186072	34.6849	34.6883	-0.0034
4600.8	1.4969	3.189761	34.6789	1.4969	3.190256	34.6849	34.6883	-0.0034
4809.4	1.5119	3.19792	34.6795	1.5119	3.198417	34.6856	34.6884	-0.0028

Module 8

Getting the Highest Accuracy Data, Continued

Overview

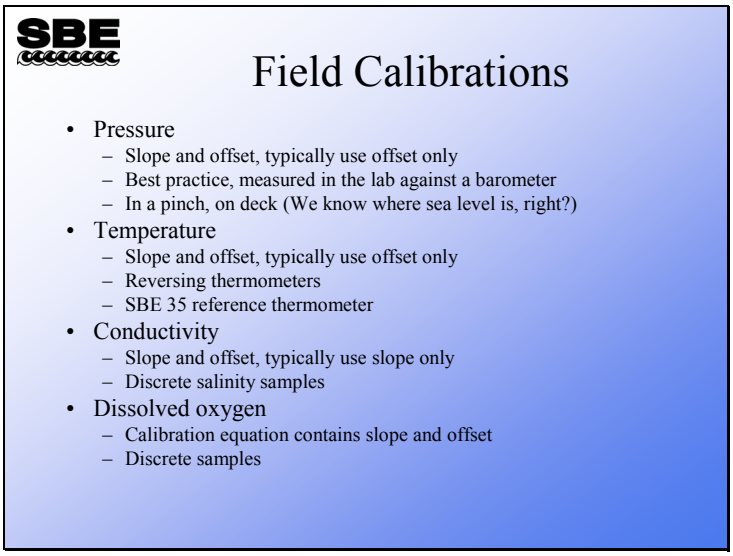


We are going to continue our discussion of methods to ensure the accuracy of profiling equipment, and then we will discuss data from autonomous profilers. We will see that the human influence on conductivity sensors is the greatest obstacle to good conductivity data.

At the end of this module, you should be able to:

- Field calibrate your CTD and Dissolved O_2 sensors.
- Have heightened awareness about the handling of your conductivity sensor.

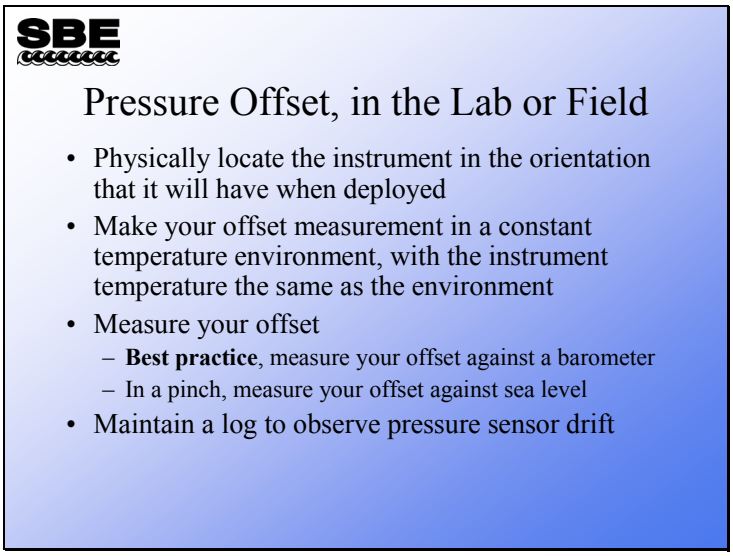
Field Calibrations



The *.con* file has entries for *slope* and *offset* for all standard sensor types except dissolved oxygen. These entries are the means to make adjustments in the sensor calibration by using field observations.

The *.con* file does not have *slope* and *offset* entries for dissolved oxygen sensors. For the SBE 43, the calibration coefficients *Soc* and *Voffset* are adjusted through comparison to Winkler titrations of discrete samples. For older oxygen sensors, *Soc* and *Boc* are adjusted.

Field Calibrations: Pressure



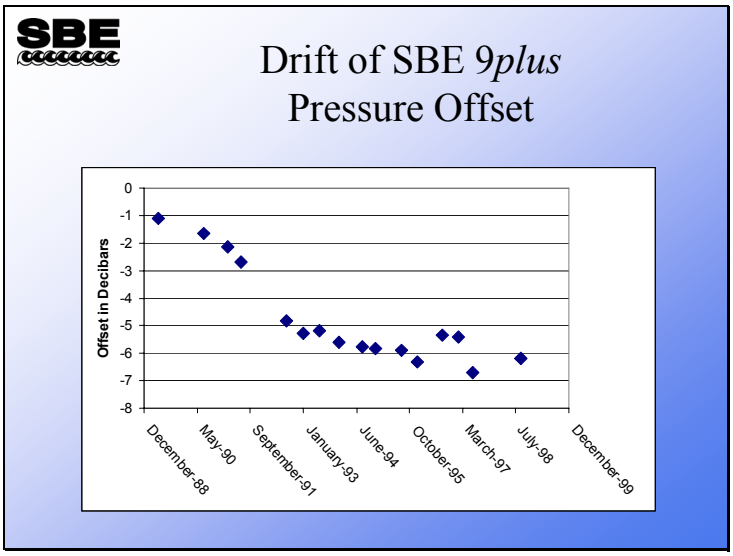
This discussion is primarily intended as a guide for the SBE 9*plus* with a Digiquartz pressure sensor. However, the technique is sound for all pressure sensor types regardless of sensitivity.

All pressure sensors are sensitive to their orientation, primarily because of gravity's pull on the fluids that fill their capillaries. To correct for this orientation effect, determine the offset with the instrument in the same orientation that it will have when you deploy it.

Pressure sensors exhibit a transient change in their output in response to changes in their environmental temperature. Sea-Bird instruments are constructed to minimize this by thermally decoupling the sensor from the body of the instrument. There is still some residual effect, and the instrument should be allowed to equilibrate in a reasonably constant temperature environment.

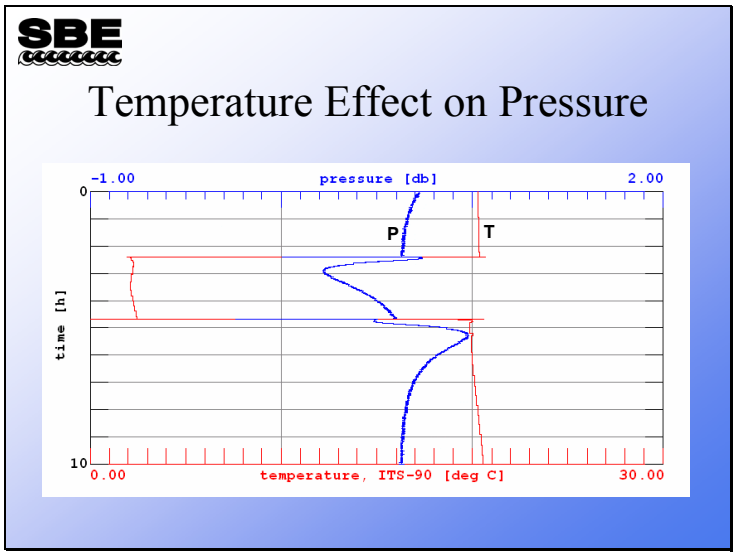
Measure the offset required to zero the pressure sensor with a barometer and convert to decibars for the entry in the *.con* file. As the next slide shows, a log of these offsets can provide good confirmation about the drift rate and show when the sensor needs maintenance.

Field Calibrations: Pressure (*continued*)



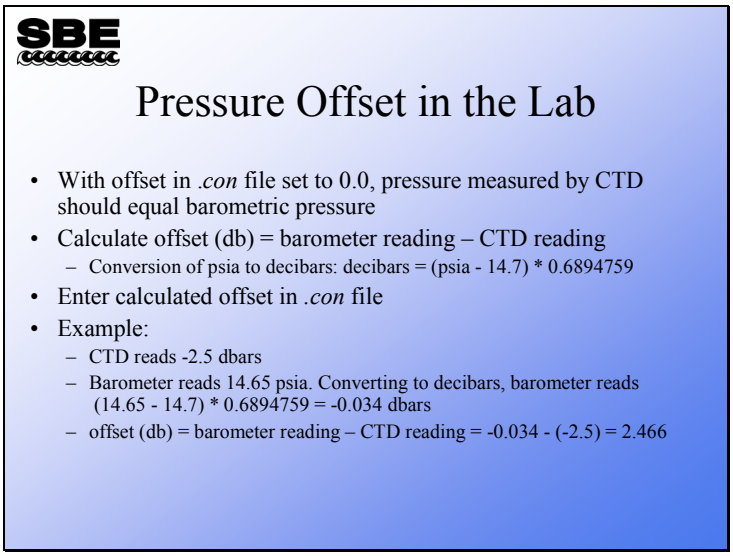
This sensor shows a typical drift until October 1995, when it begins to change in a more random manner. The random behavior indicates that it is time for a calibration and test by the factory.

Field Calibrations: Pressure (*continued*)

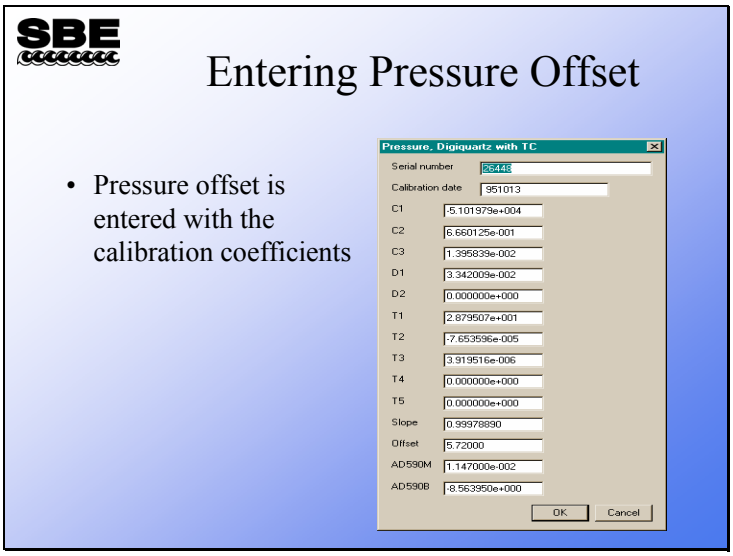


As we mentioned earlier, the SBE 9*plus* pressure sensor exhibits small pressure excursions in response to rapid changes in temperature. If you are attempting to determine an offset for the pressure sensor in the field, you must take care that the instrument is equilibrated in temperature with its environment. As the plot shows, if you pull the instrument up from a very cold depth, it can take 4 to 5 hours for the pressure sensor to completely equilibrate. It is for this reason that Sea-Bird recommends a laboratory determination of offset in relation to a barometer.

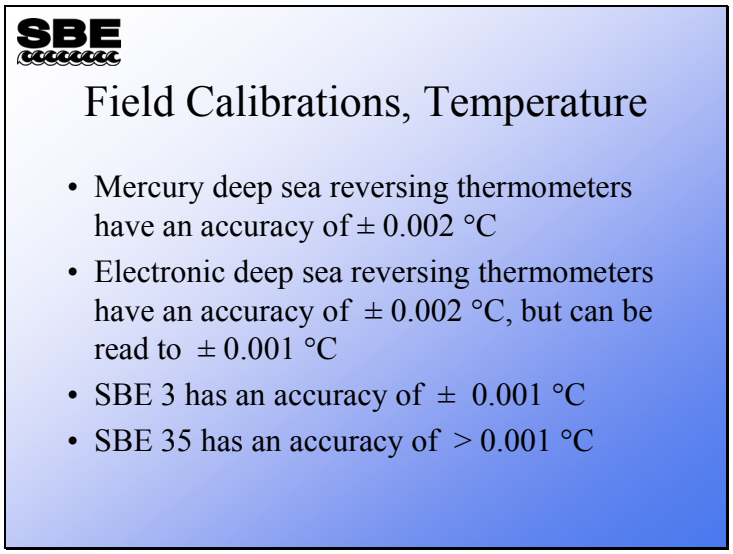
Field Calibrations: Pressure (*continued*)



Field Calibrations: Pressure (*continued*)



Field Calibrations: Temperature



Traditional mercury deep-sea reversing thermometers are not capable of resolving temperature accurately enough to field calibrate the SBE 3. Nor do electronic deep-sea reversing thermometers have the accuracy for field calibrations. Sea-Bird markets a deep-sea standards thermometer, the SBE 35, which has the physical configuration to allow calibration in a triple point cell or a gallium melt cell.

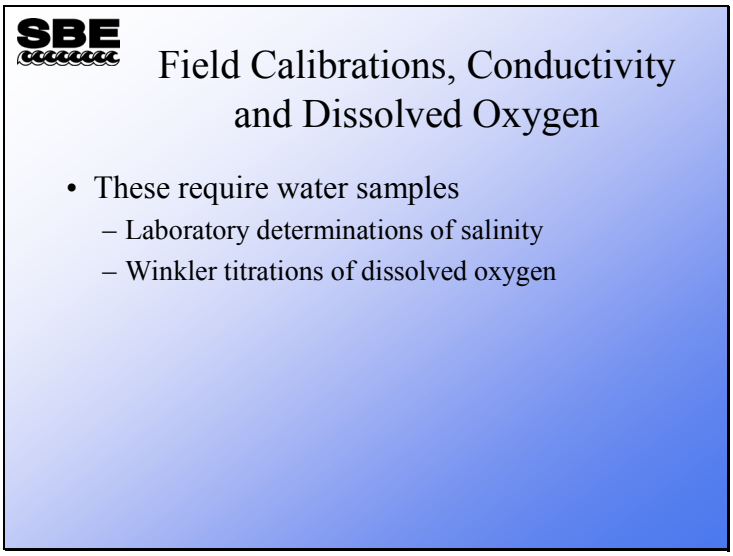
However, you have to be very careful making field calibrations of deep-sea thermometers, because the distance between the two thermometers can make a great difference in the water they measure. Additionally, the part of the ocean used for comparison must change temperature very slowly, to avoid artifacts due to location on the sampling package and time constants.

A further difficulty is that the part of the ocean that changes most slowly is the deepest and coldest part. This means that field calibrations may be carried out over a small part of the temperature range of interest. The paper cited below discusses the authors' experiences and the issues discussed above.

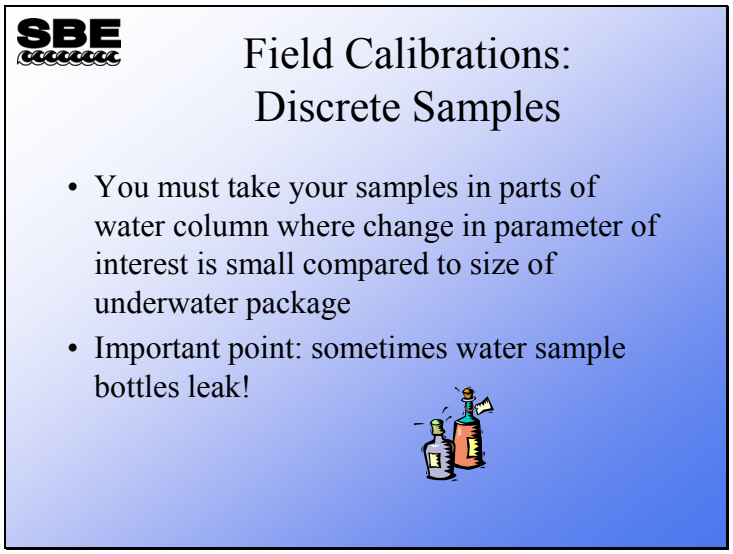
It is best to use pre- and post-cruise calibrations for correction of temperature data.

In-situ Temperature Calibration: A Remark on Instruments and Methods, G. Budeus and W. Schneider, Alfred-Wegener-Institut für Polar- und Meeresforschung, Bremerhaven, Germany, Int. WOCE Newsletter, #30, March 1998, 16-18.

Field Calibrations: Conductivity and Dissolved Oxygen



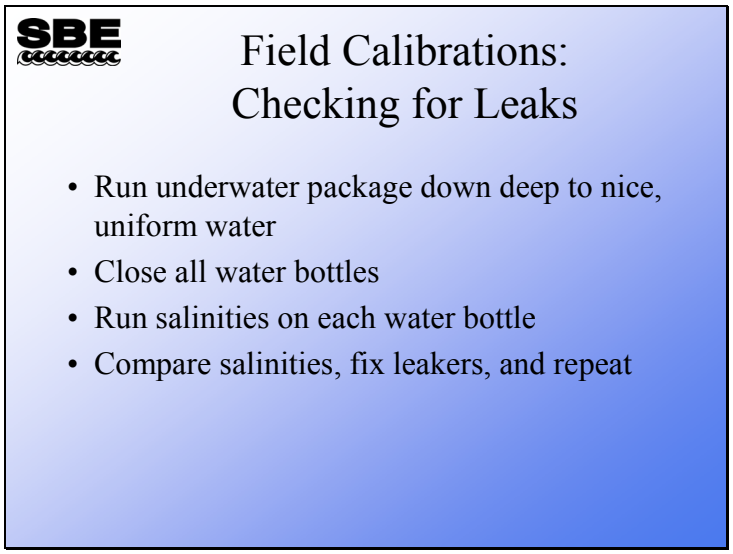
Field Calibrations: Discrete Sampling



Most instrument packages are more than a meter tall. If you take your samples for field calibrations in a part of the water column where the salinity or oxygen concentration is changing rapidly, you will not get a good sample for calibrating. Not only is there mixing of the water inside the water sampler, but you will be comparing a large mixed sample with a virtual point sample from the sensors.

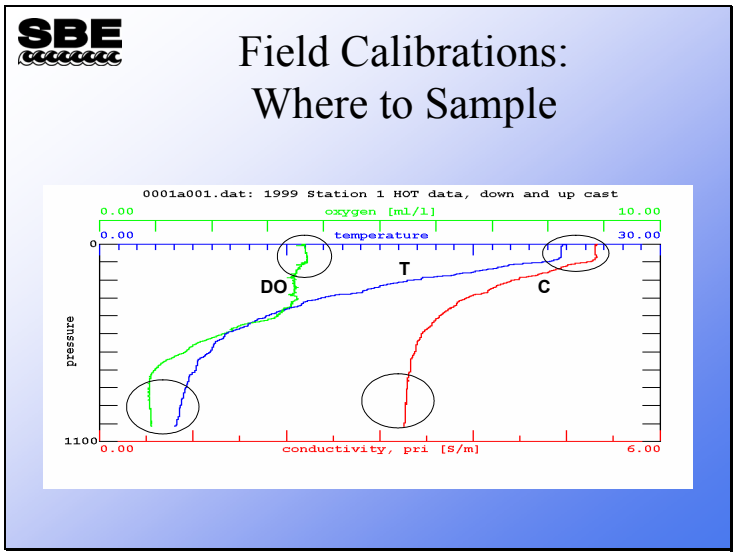
Often the surface of the ocean is well mixed and provides good field calibrations for one end of the scale. And the deep ocean offers plenty of water where salinity and oxygen is changing very slowly for the other end of the scale.

Field Calibrations: Discrete Sampling (*continued*)



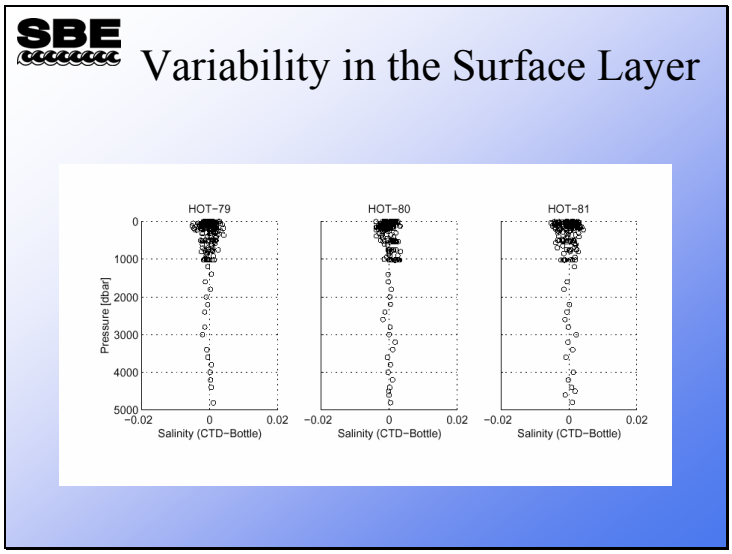
A water bottle consists of a plastic tube with top and bottom caps. The caps are sealed with o-rings and held in place with a spring or elastic tube. Consider that the instrument package moves through the water column on average at 1 meter per second, and faster when the ship heaves. Leaky o-rings or weak springs can allow an exchange of water between the captured sample and the ocean as the instrument package is brought to the surface. It is good practice to take the instrument package down to a depth where the salinity is changing very slowly, and then close all the sample bottles. Using this method, any leakers will be obvious when the laboratory salinity samples are run. Repair or replace any bottles that leak, or only use bottles that have been shown not to leak in field calibrations.

Field Calibrations: Discrete Sampling (*continued*)



Use samples from depths showing the most uniformity in the parameter you are most interested in.

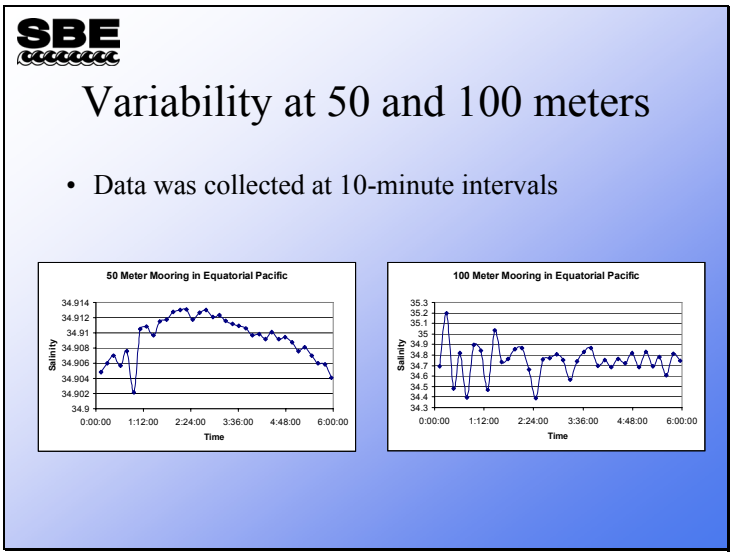
Field Calibrations: Conductivity



These data are taken from 3 cruises off Hawaii. The problem with using the surface layer to correct CTD conductivity is obvious.

L. Tupas, et al., Hawaii Ocean Time-series Data Report 9, 1997. University of Hawaii, School of Ocean and Earth Science and Technology. page 21

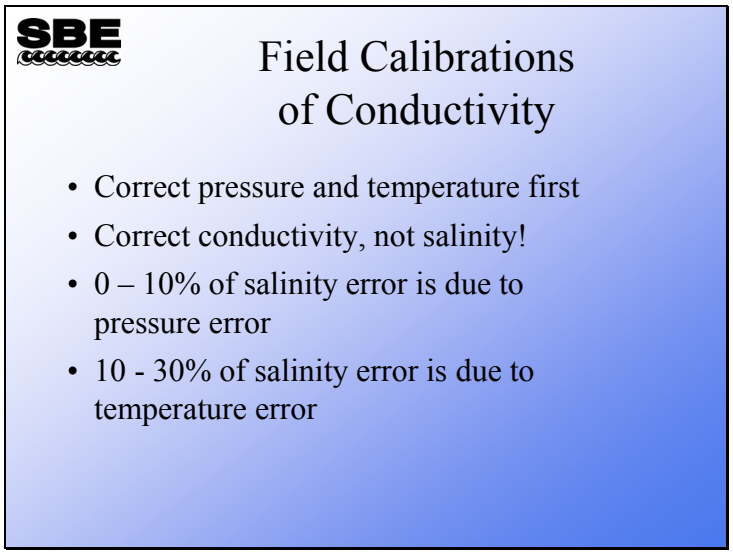
Field Calibrations: Conductivity (*continued*)



This slide shows data from a mooring near the equator. The 50-meter mooring data shows a change in salinity that might be from tidal influence. The change observed here is of similar magnitude to the correction that might be applied to CTD data based on the difference between discrete samples and the CTD.

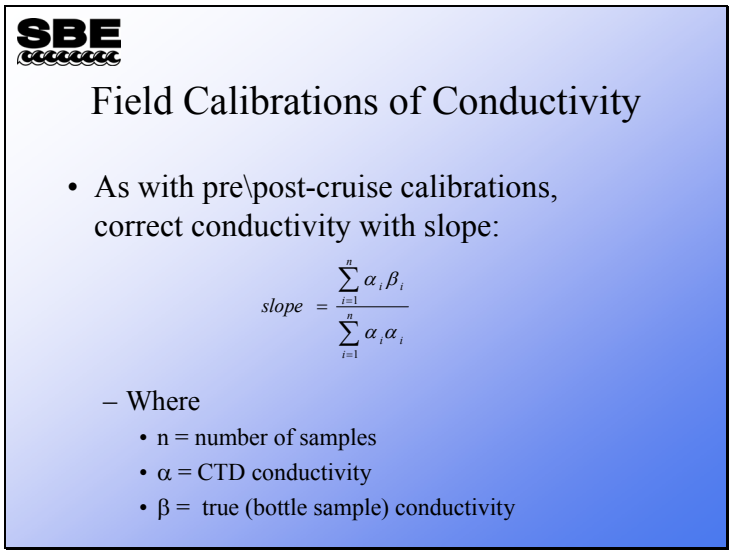
The 100-meter mooring data shows changes in salinity that might be caused by internal waves in the thermocline. Changes of this magnitude over this time interval will cause a large and real difference between the upcast and downcast.

Field Calibrations: Conductivity (*continued*)



Because the equation that converts the conductivity sensor output from frequency to conductivity includes pressure and temperature as well as frequency, it is necessary to correct pressure and temperature before correcting conductivity. The usual reason for collecting conductivity data is to calculate salinity. Examining the salinity equation, up to 10% of a possible salinity error could be in the pressure term, 10 – 30% in the temperature term, and the remainder in the conductivity term. It is well worth correcting pressure and temperature in addition to conductivity.

Field Calibrations: Conductivity (*continued*)



The summation symbol, Sigma (∑), denotes the addition of a series of values. The script on the bottom of the ∑ is the index of the starting value, the script on the top is the ending value. We wish to use all suitable samples so we will start with one and end with n, the total number of samples.

Example:

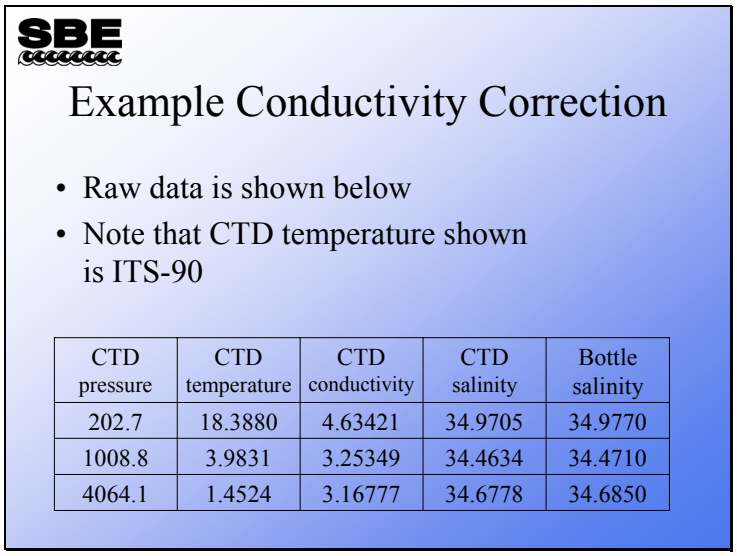
Suppose we had 2 salinity samples to go with our CTD cast. The conductivity of these water samples is determined by a laboratory salinometer and paired with CTD data from the corresponding depths.

CTD Conductivity	Salinometer Conductivity
2.1234	2.1244
4.1234	4.1244

$$slope = \frac{(2.1234 * 2.1244) + (4.1234 * 4.1244)}{(2.1234 * 2.1234) + (4.1234 * 4.1234)}$$

$$slope = 1.00029$$

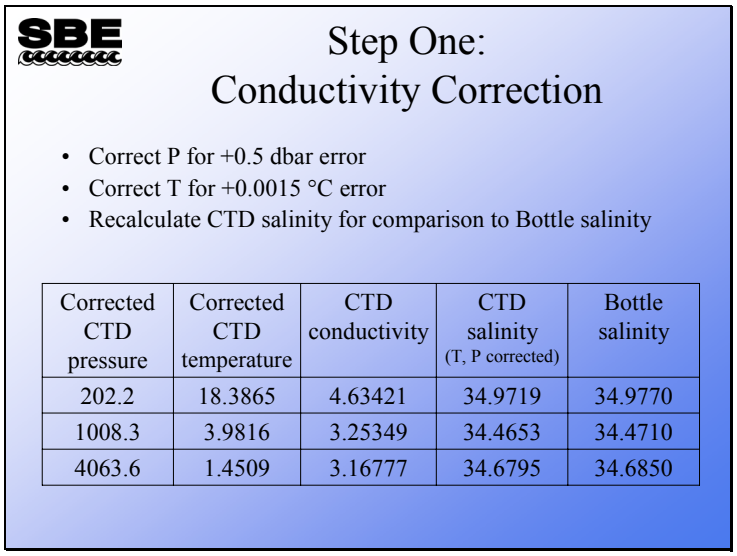
Field Calibrations: Conductivity (*continued*)



CTD pressure	CTD temperature	CTD conductivity	CTD salinity	Bottle salinity
202.7	18.3880	4.63421	34.9705	34.9770
1008.8	3.9831	3.25349	34.4634	34.4710
4064.1	1.4524	3.16777	34.6778	34.6850

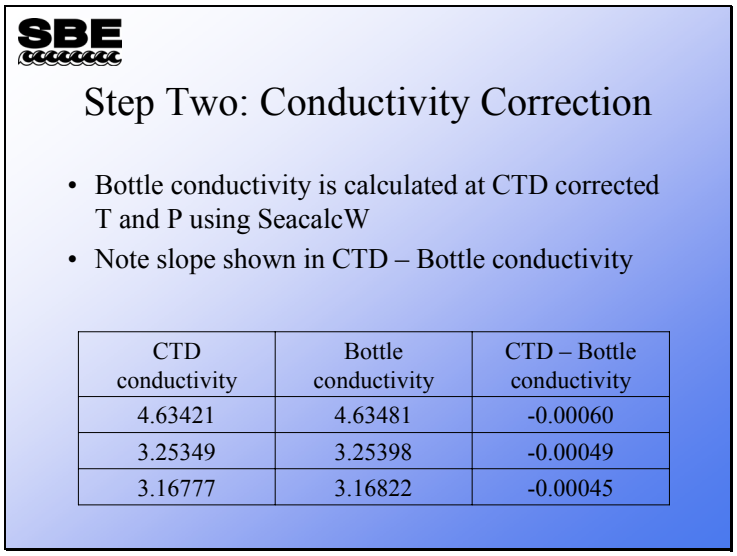
This example is a slight variation of the example in Application Note 31. You would find the CTD data in your *.ros* file, which is created by the Data Conversion module.

Field Calibrations: Conductivity (*continued*)



Temperature and pressure are corrected first. CTD salinity is recalculated only for comparison to the bottle salinity. We will be correcting conductivity, not salinity.

Field Calibrations: Conductivity (*continued*)



The numbers in the column labeled *CTD – Bottle conductivity* are not constant. Rather, they have the slope we have been harping on.

Let's look at calculating the slope:

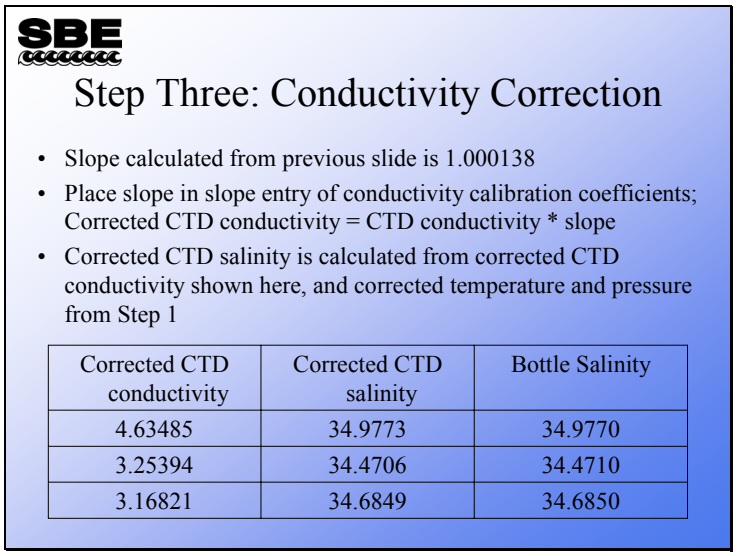
$$slope = \frac{\sum_{i=1}^{n} \alpha_i \beta_i}{\sum_{i=1}^{n} \alpha_i \alpha_i}$$

Slope =

$$\frac{(4.63421 * 4.63481) + (3.25349 * 3.25398) + (3.16777 * 3.16822)}{(4.63421 * 4.63421) + (3.25349 * 3.25349) + (3.16777 * 3.16777)}$$

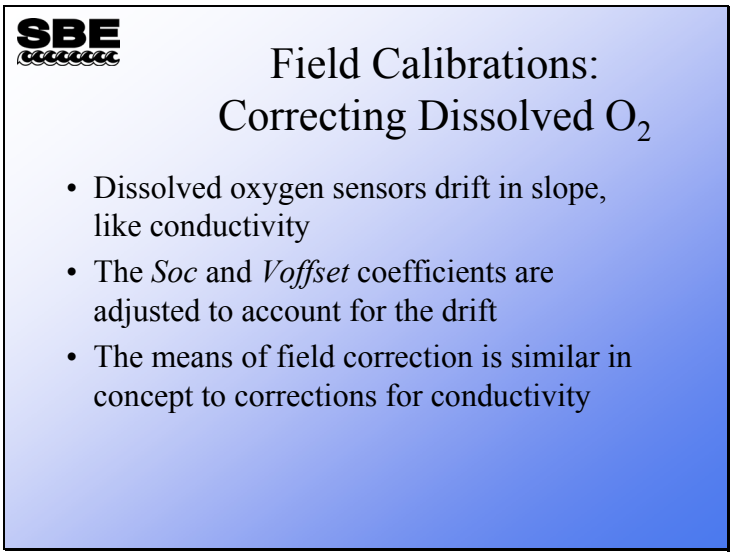
= 1.000138

Field Calibrations: Conductivity (*continued*)



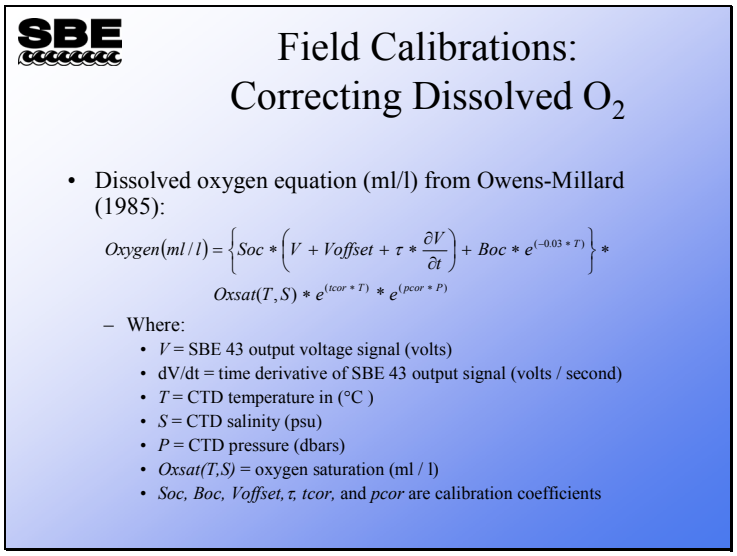
The correction puts the CTD salinities much closer to the bottle salinities. You may be wondering what to do if you collect bottle salinities with every cast and have many casts in a cruise. It would be a bit onerous to make this calculation for every cast and process each cast with a different offset. Usually, making this calculation and changing the slope value in the conductivity sensor's calibration coefficients each week is sufficient. However as we have discussed, fouling is often *an event*. This being the case, careful scrutiny of your data is warranted to ensure that you catch these events and change the slope correction accordingly.

Field Calibrations: Dissolved Oxygen



There are two mechanisms at work in oxygen sensor drift. Since the electrode remains polarized throughout its life, the electrolyte gets used up and there is some diminishing of the sensitivity of the electrode itself. There is also fouling, which can be *an event* like in the conductivity example. Check your oxygen data with bottle samples and make corrections to *Soc* at your discretion.

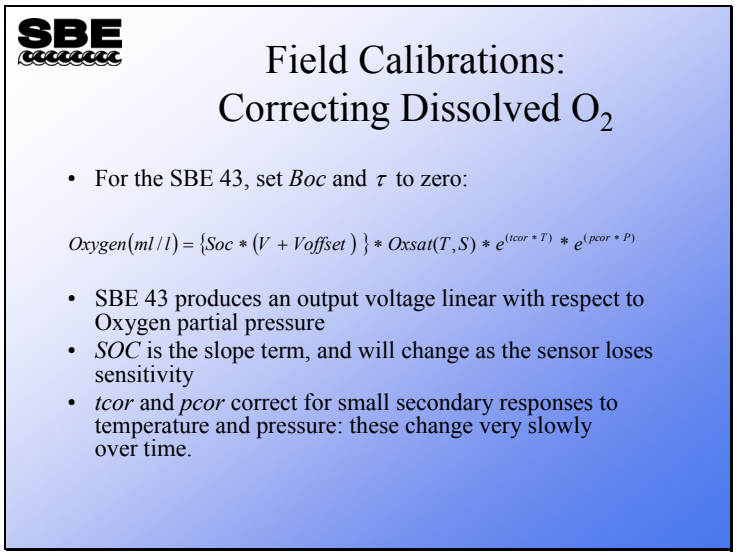
Field Calibrations: Dissolved Oxygen (*continued*)



The basis for calculating dissolved oxygen is work done by Owens and Millard (1985). This equation includes a blank or zero oxygen term, *Boc*, and a term that is proportional to the first derivative of the oxygen sensor output voltage, $\tau * \delta V/\delta t$. The *Boc* term is redundant for the SBE 43, because the sensor output is offset by a *Voffset* term which takes the place of *Boc*.

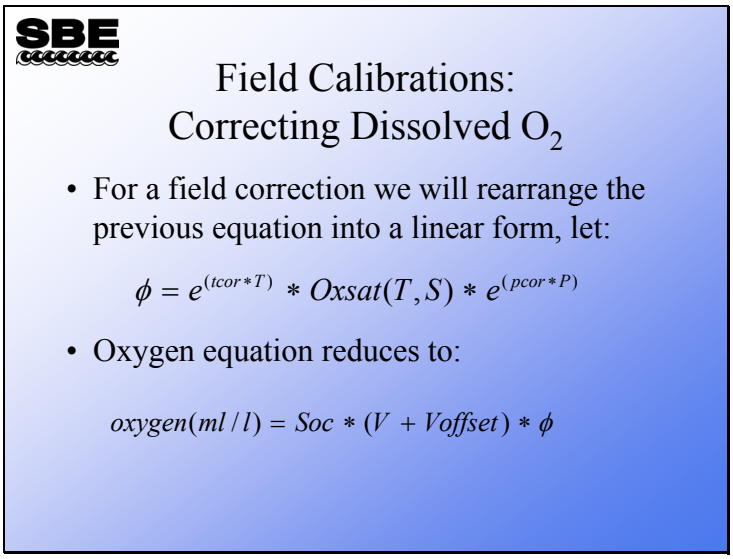
The term that is proportional to the first derivative of the sensor output was introduced to sharpen the response of the sensor to rapid changes in oxygen concentration. The SBE 43 was designed for profiling applications and does not suffer the poor response times of previous sensors. In consideration of this, the derivative term is left out of the equation used to calculate oxygen concentration from output voltage for the SBE 43.

Field Calibrations: Dissolved Oxygen (*continued*)



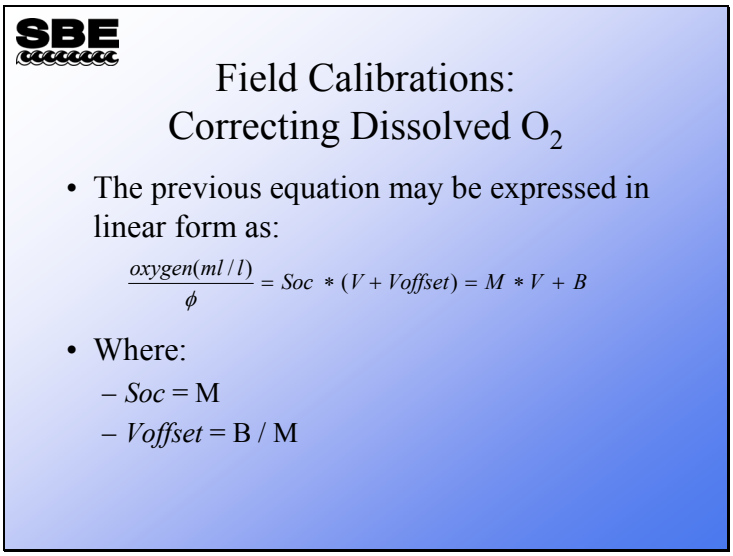
The SBE 43 is expected to provide an output voltage that is linear with respect to oxygen concentration. Normal calibration drift manifests itself as a loss of sensitivity and is evident as a change of slope and offset in the linear relationship between oxygen concentration and voltage output. The coefficients *tcor* and *pcor* correct for small secondary responses to temperature and pressure. Because these coefficients change very slowly over time, the values given on the SBE 43 calibration certificate will be used in this analysis.

Field Calibrations: Dissolved Oxygen (*continued*)



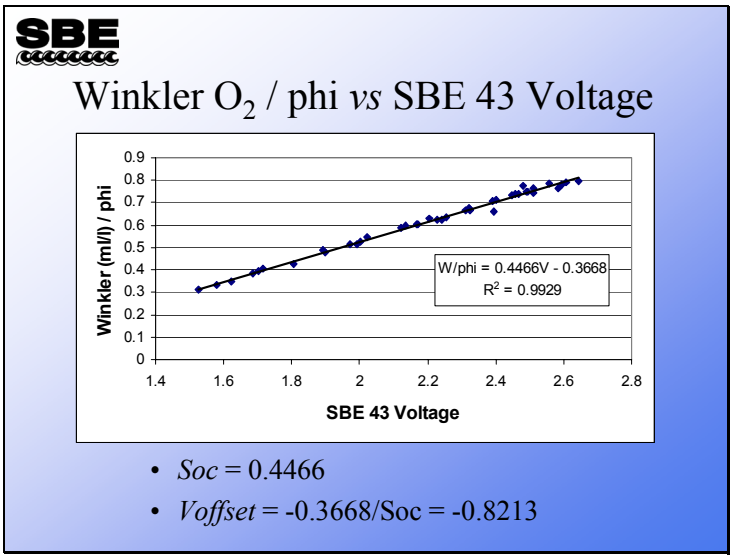
Our goal is to rearrange the equation into a linear form that we can use in a linear regression of Winkler titration dissolved oxygen versus SBE 43 voltage output. To simplify this we will collect terms and express oxygen saturation and the corrections for pressure and temperature as *phi*.

Field Calibrations: Dissolved Oxygen (*continued*)



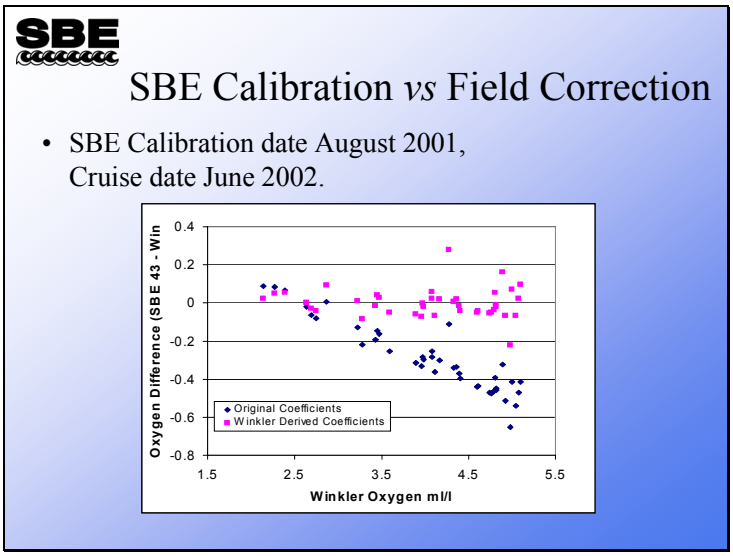
Finally, Winkler titration values divided by *phi* is the independent variable and SBE 43 output voltage is the dependent variable. Note that *Soc* and *Voffset* are constants, so the right side of the equation is expressed as a slope (*Soc*) multiplied by a variable voltage plus a constant offset (*Voffset*).

Field Calibrations: Dissolved Oxygen (*continued*)



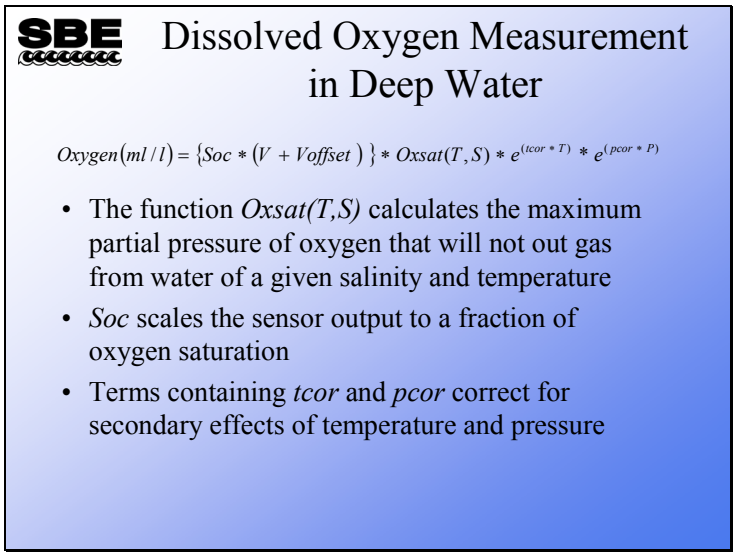
Here is a plot and regression of some data gathered in Puget Sound. Even though Puget Sound is not a well-mixed environment, there is a very strong relationship between Winkler O_2 / *phi* and SBE 43 Voltage.

Field Calibrations: Dissolved Oxygen (*continued*)



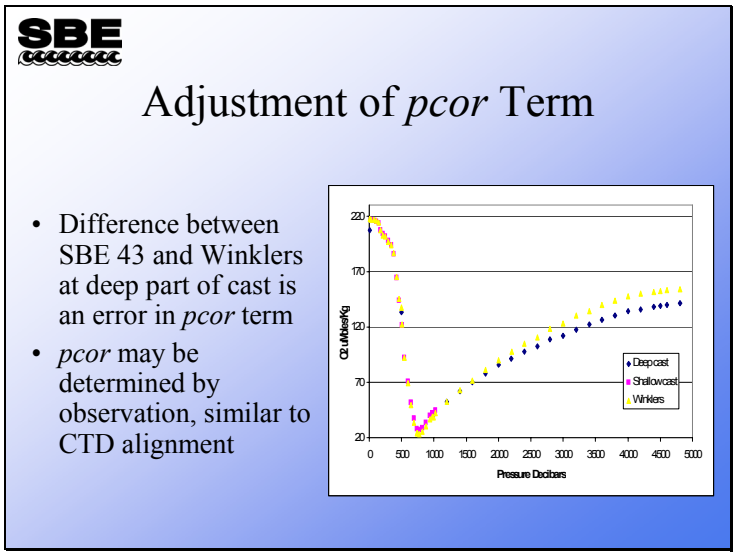
This plot shows the improvement in agreement between the Winkler titrations of dissolved oxygen and the SBE 43 measurement of dissolved oxygen after application of the Winkler-derived *Soc* and *Voffset*. The blue diamonds are the difference between the Winkler values and the SBE 43 values using *Soc* and *Voffset* from the most recent calibration. The pink squares are the difference between the Winkler values and the SBE43 values using the derived *Soc* and *Voffset*.

Field Calibrations: Dissolved Oxygen (*continued*)



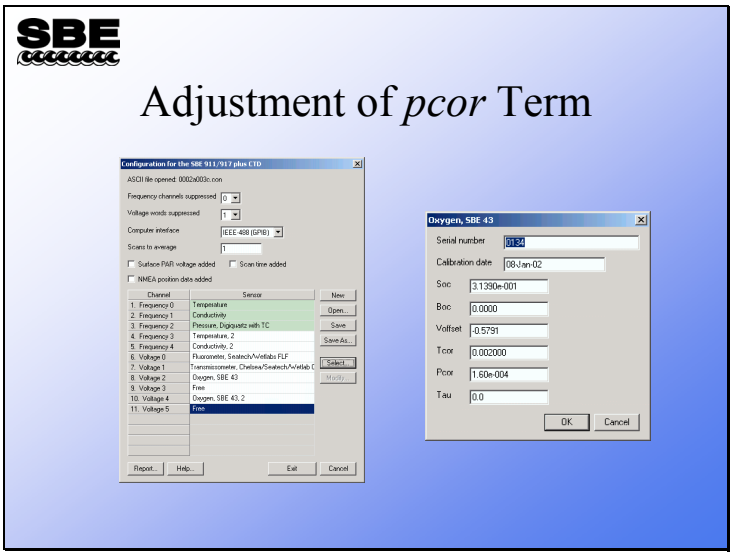
Recall the dissolved oxygen equation; basically it is a scaling of oxygen saturation based on sensor output with a correction for temperature sensitivity and for pressure sensitivity. In the following discussion we will explore the pressure correction and learn how to fine tune it with adjustments to *pcor*.

Field Calibrations: Dissolved Oxygen (*continued*)

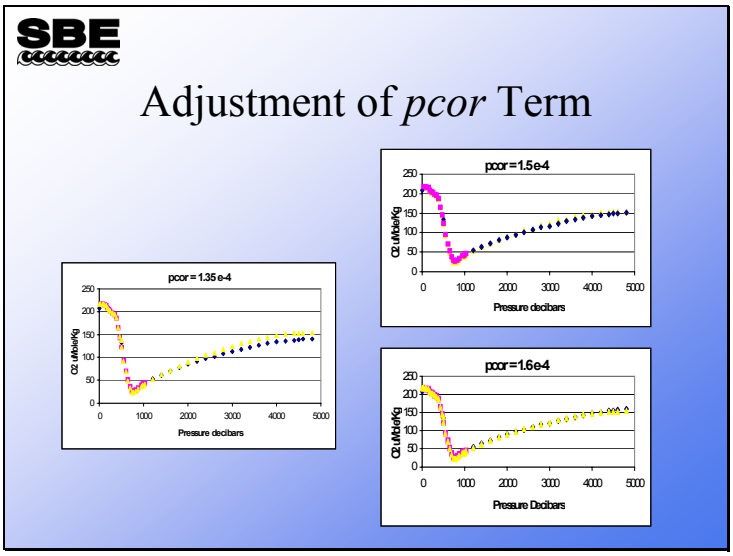


As you might imagine, the term in the equation that corrects for pressure effects has little effect in the upper part of the profile. The slide above illustrates that as the pressure increases, the response of the instrument deviates from the Winkler titrations. We can improve the agreement of the SBE 43 and the Winkler titrations by adjusting *pcor*.

Field Calibrations: Dissolved Oxygen (*continued*)

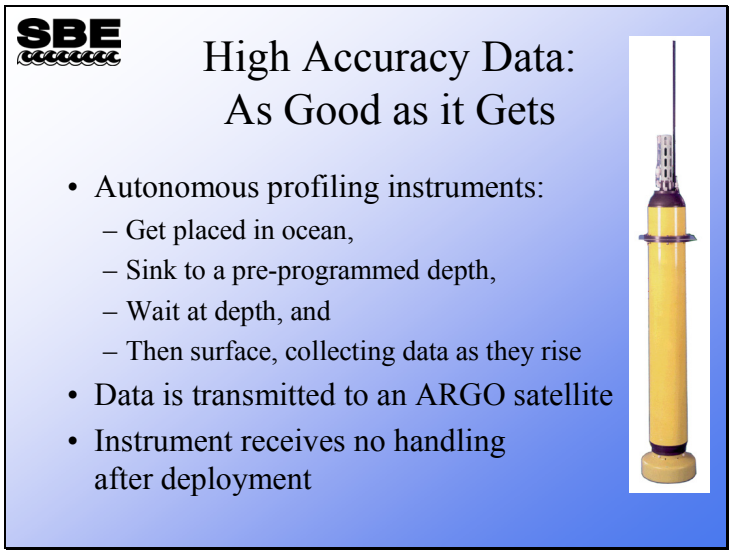


Field Calibrations: Dissolved Oxygen (*continued*)



We can make the adjustment to *pcor* empirically. The plots above show the discrepancy between the SBE 43 calculated oxygen and the Winkler titrations with a series of *pcor* values. Clearly, the middle value of 1.5×10^{-4} gives the best agreement.

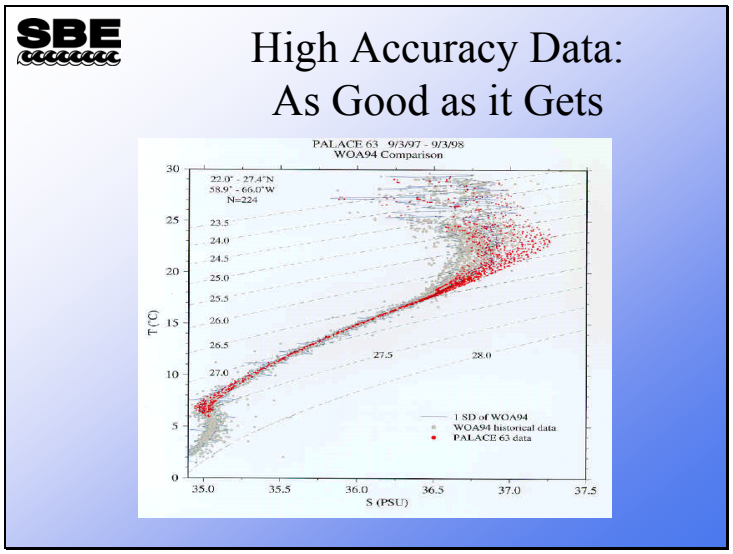
PALACE Float: No Conductivity Drift (almost)



These CTDs have a significant advantage over the usual deployments with regard to conductivity drift. They are deployed from ships with their conductivity cells full of de-ionized water, and have no contact with ships or humans for the remainder of their lives. They are never exposed to the sea surface near a ship with its oil film. Finally, their cells are never allowed to dry, so the electrodes are always stored in biology-resistant water.

The consequence of this is that their conductivity sensors drift negligibly or not at all.

PALACE Float: Compared to Historical Data



Note the low scatter in the mid-region compared to historical CTD data. Also, note the shift in surface values, PALACE being saltier than historical data.

Activity: Correct CTD Conductivity with Water Samples

Pressure db	CTD Temp	CTD Cond	Uncorrected CTD Salinity	Water Bottle Salinity	Water Bottle Cond	Corrected CTD Temp	Corrected CTD Cond	Corrected CTD Salinity	Corrected CTD Salinity- Water Bottle Salinity
4.9	24.0798	5.23638	35.1885	35.2055		24.0798			
519	6.6922	3.43991	34.0769	34.0848		6.6922			
850.6	4.4142	3.27659	34.3667	34.3738		4.4142			
1000.8	4.003	3.25475	34.4616	34.472		4.003			
1202.3	3.5221	3.22482	34.5083	34.5148		3.5221			
1401	3.039	3.19378	34.5452	34.5503		3.039			
1599.6	2.6724	3.1719	34.5692	34.5769		2.6724			
1999.1	2.1309	3.1445	34.6131	34.6194		2.1309			
2400.2	1.7884	3.13273	34.6392	34.6463		1.7884			
2798.9	1.5911	3.13234	34.6563	34.6645		1.5911			
3200.1	1.4927	3.1397	34.6674	34.676		1.4927			
3600.3	1.4587	3.15175	34.6737	34.6829		1.4587			
4001.5	1.4537	3.16568	34.6772	34.6853		1.4537			
4401.9	1.4766	3.18142	34.6790	34.6871		1.4766			
4500.7	1.4868	3.18558	34.6788	34.6883		1.4868			
4600.8	1.4969	3.18976	34.6789	34.6883		1.4969			
4809.4	1.5119	3.19792	34.6795	34.6884		1.5119			

1. What temperature scale is CTD temperature reported in? What temperature scale is used to calculate conductivity?

2. Use SeaCalcW to calculate “Water Bottle Conductivity” using “Corrected CTD Temp” and “Water Bottle Salinity”.

3. Calculate a conductivity correction slope based on the shaded portion of the table. We are using 3 data rows in class as a quick exercise. Normally, how much of the table would you use? Recall pages 17 and 20.

CTD Conductivity Corrected With Water Samples

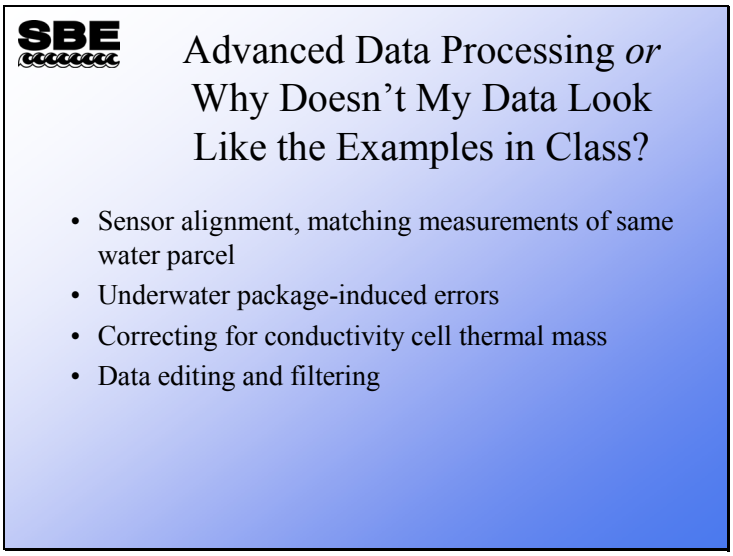
Pressure db	CTD Temp	CTD Cond	Uncorrected CTD Salinity	Water Bottle Salinity	Water Bottle Cond	Corrected CTD Temp	Corrected CTD Cond	Corrected CTD Salinity	Corrected CTD Salinity- Water Bottle Salinity
4.9	24.0798	5.23638	35.1885	35.2055	5.23862	24.0798	5.23763	35.1980	-0.0075
519	6.6922	3.43991	34.0769	34.0848	3.44062	6.6922	3.44073	34.0861	0.0013
850.6	4.4142	3.27659	34.3667	34.3738	3.27720	4.4142	3.27737	34.3758	0.0020
1000.8	4.003	3.25475	34.4616	34.472	3.25563	4.003	3.25553	34.4708	-0.0012
1202.3	3.5221	3.22482	34.5083	34.5148	3.22537	3.5221	3.22559	34.5175	0.0027
1401	3.039	3.19378	34.5452	34.5503	3.19420	3.039	3.19454	34.5544	0.0041
1599.6	2.6724	3.1719	34.5692	34.5769	3.17253	2.6724	3.17266	34.5785	0.0016
1999.1	2.1309	3.1445	34.6131	34.6194	3.14502	2.1309	3.14525	34.6223	0.0029
2400.2	1.7884	3.13273	34.6392	34.6463	3.13331	1.7884	3.13348	34.6484	0.0021
2798.9	1.5911	3.13234	34.6563	34.6645	3.13301	1.5911	3.13309	34.6655	0.0010
3200.1	1.4927	3.1397	34.6674	34.676	3.14039	1.4927	3.14045	34.6767	0.0007
3600.3	1.4587	3.15175	34.6737	34.6829	3.15250	1.4587	3.15250	34.6829	0.0000
4001.5	1.4537	3.16568	34.6772	34.6853	3.16634	1.4537	3.16644	34.6864	0.0011
4401.9	1.4766	3.18142	34.6790	34.6871	3.18208	1.4766	3.18218	34.6883	0.0012
4500.7	1.4868	3.18558	34.6788	34.6883	3.18636	1.4868	3.18634	34.6881	-0.0002
4600.8	1.4969	3.18976	34.6789	34.6883	3.19054	1.4969	3.19052	34.6881	-0.0002
4809.4	1.5119	3.19792	34.6795	34.6884	3.19865	1.5119	3.19868	34.6888	0.0004

Note: For Shaded section of table:
Sum of CTD conductivity * Water Sample conductivity = 30.55649
Sum of CTD conductivity * CTD conductivity = 30.54918
Ratio used to correct CTD conductivity = 1.000239

Module 9

Advanced Data Processing

Overview



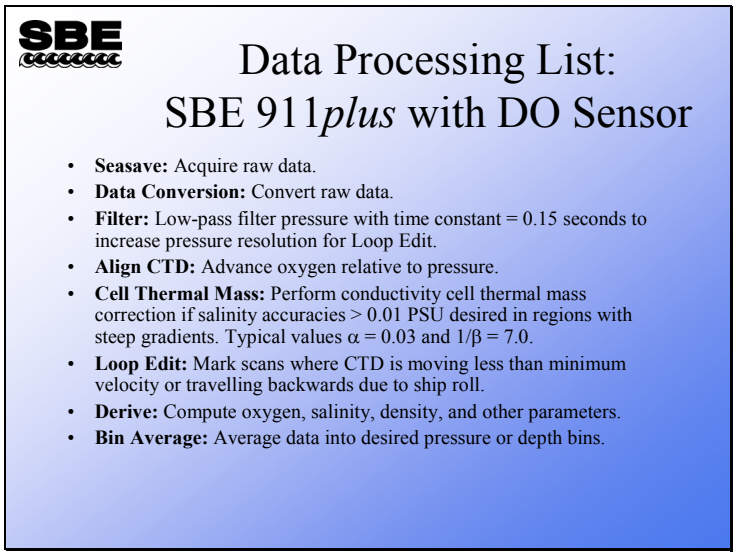
This section of the course is the final topic in profiling. Some of it is fine tuning of your data to remove small artifacts of frequency counting, plumbing, and sensor physics. We will also discuss the removal of the fairly gross effects of ship heave. Understanding these topics will help explain most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

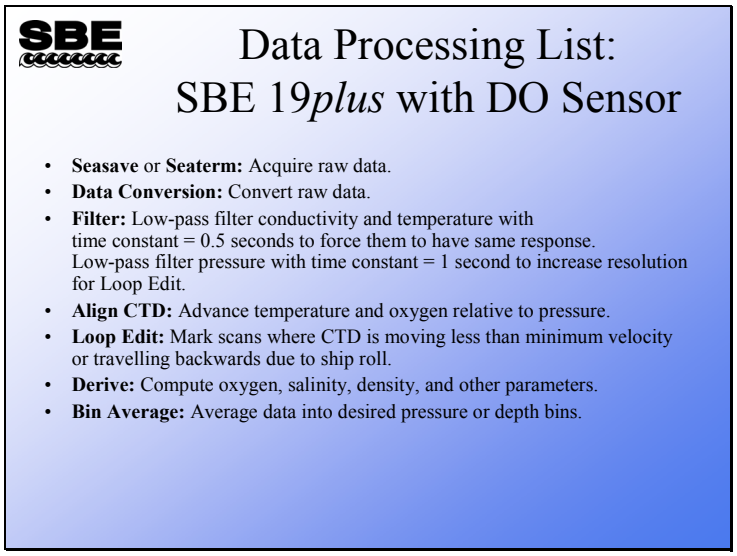
Data Processing Steps: SBE 9*plus* / 11*plus*



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.

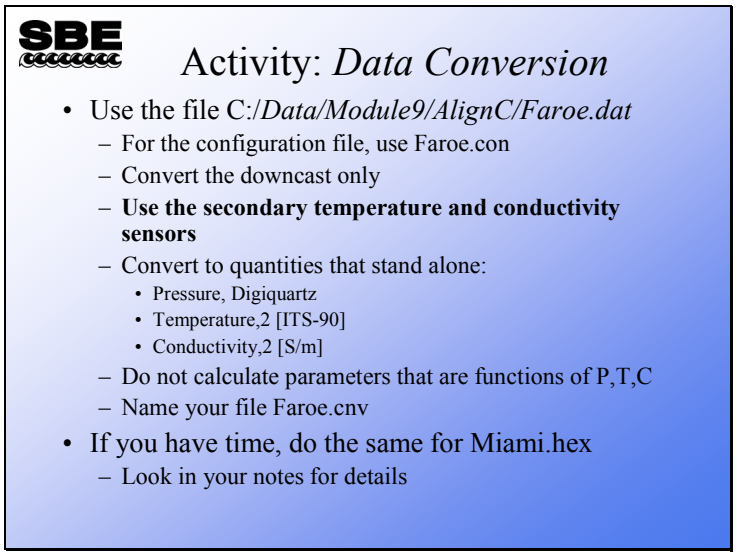
Note that the data is bin averaged before the major derived quantities are computed. Salinity, density, etc, are functions of T, C, and P; these are calculated on the final values of T, C, and P rather than the intermediate values. We'll talk a bit more about this at the end of the module.

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

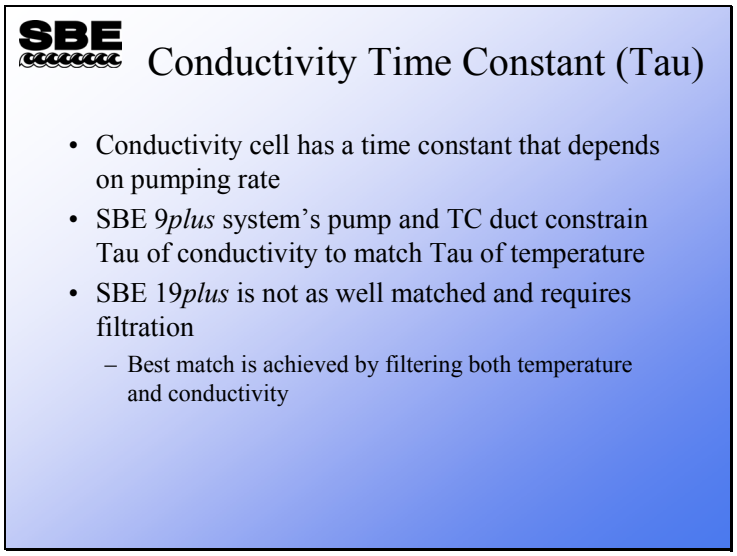


We are preparing to operate on the data with an application that moves the T and C data streams relative to the pressure data stream. Calculation of parameters that are functions of T, C, and P is not useful at this stage. Further, it will complicate and confuse things to have them in the data set before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

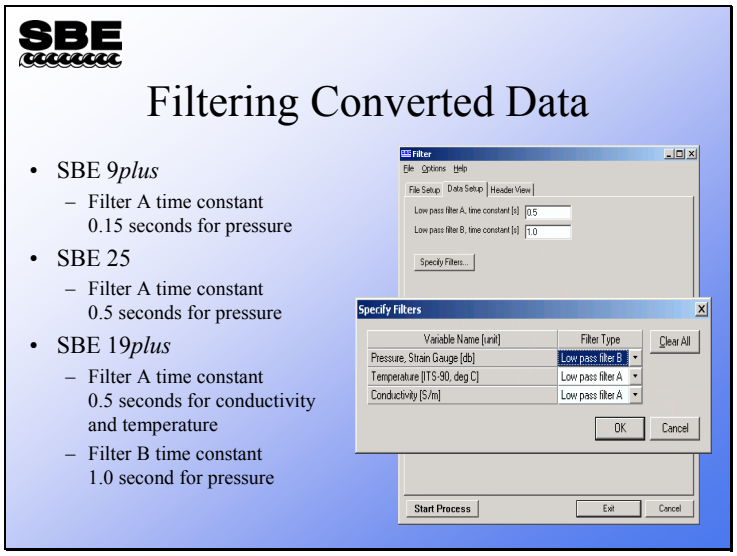
- Downcast only
- Convert… Pressure, Strain Gauge [db], Temperature [ITS-90], Conductivity [S/m]
- Name your file Miami.cnv

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*)

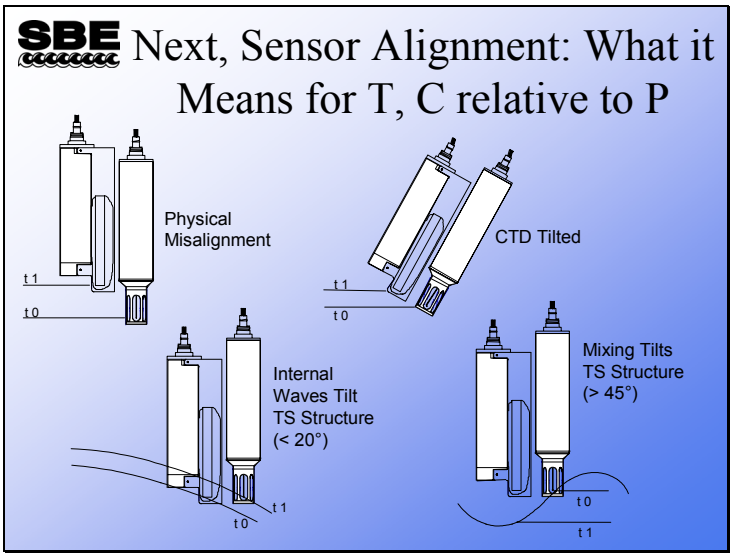


Filtering is done for two reasons:

- 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:

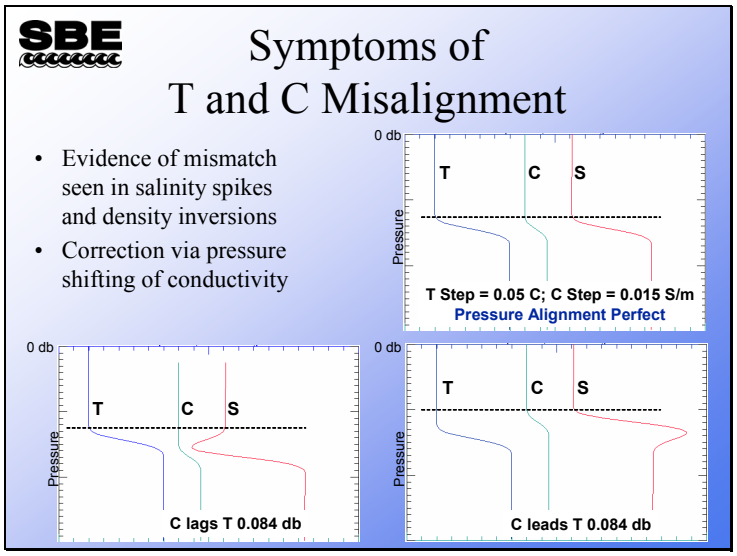
  - SBE 9*plus* – samples at 24 Hz (0.04167 sec), 4 x 0.04167 ≈ 0.15 sec
  - SBE 25 – samples at 8 Hz (0.125 sec), 4 x 0.125 = 0.5 sec
  - SBE 19*plus* – samples at 4 Hz (0.25 sec), 4 x 0.25 = 1 sec

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



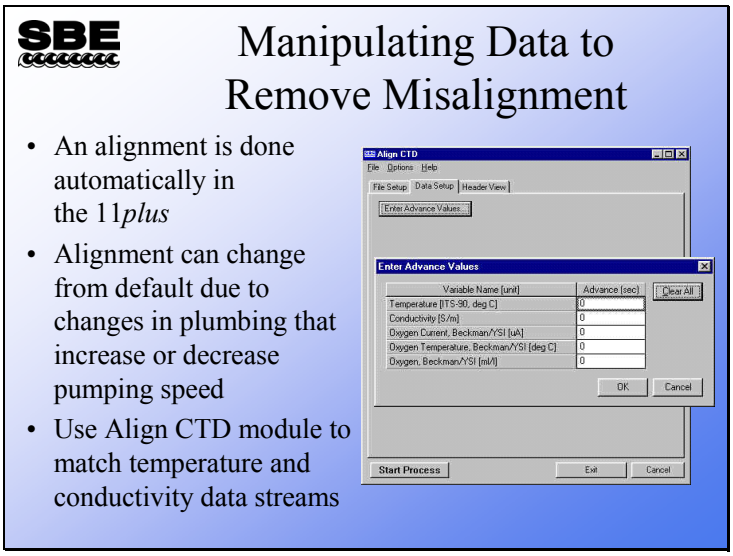
Here is an artificial data set with a step change in temperature and conductivity. Temperature is the blue trace, conductivity is the green, and salinity is the red.

- 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

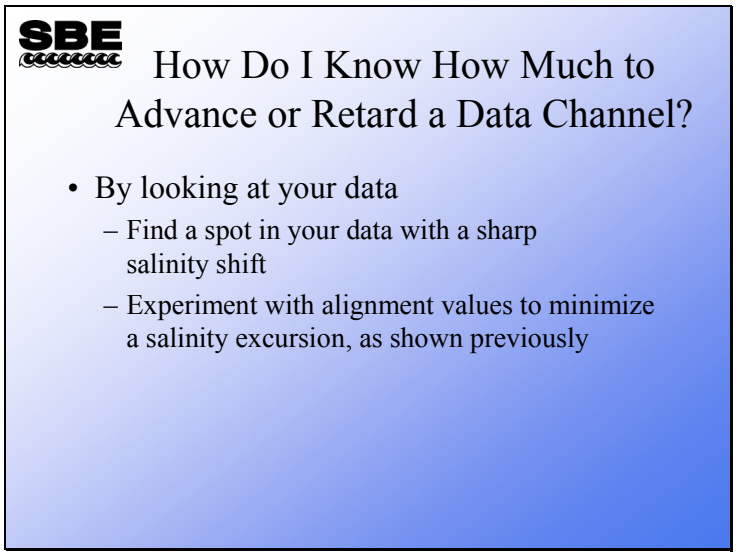


Because the 911*plus* system is well characterized, an alignment of the data stream is done automatically in the 11*plus* before data is transmitted to your computer. With the TC duct in place, an alignment of 1.75 data scans (or 0.073 seconds) is done on incoming data. A linear interpolation between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

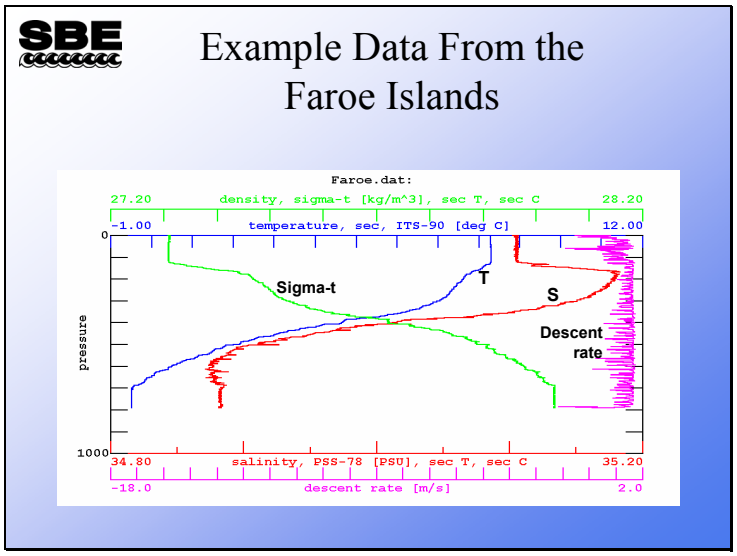
Misalignment that differs from the nominal values can arise from plumbing changes, which can influence pumping speed. A slower pumping speed increases a water parcel's residence time in the TC plumbing, and will require a larger shift in data scans. A faster pumping speed will decrease the residence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

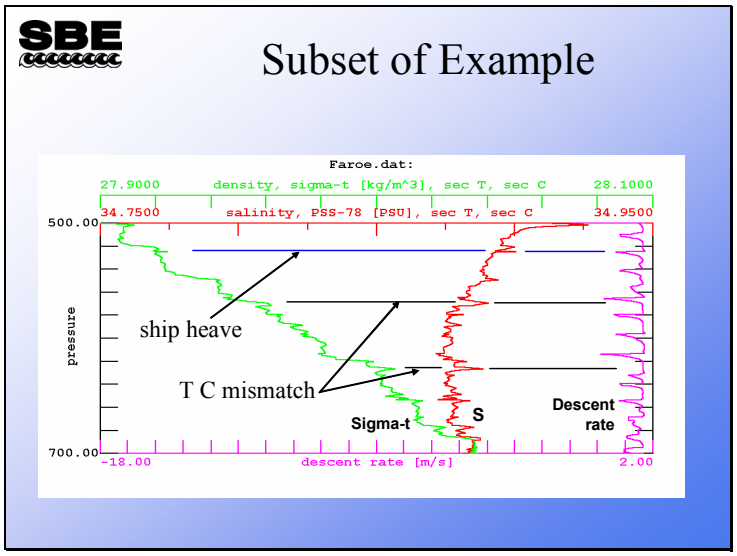


This data set was collected with the secondary T and C sensors of a 911*plus* off the Faroe Islands in 1995. Note the spiky salinity data and the density inversions. These arise from two phenomena: a mismatch between temperature and conductivity samples, and ship heave. The ship heave causes water to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

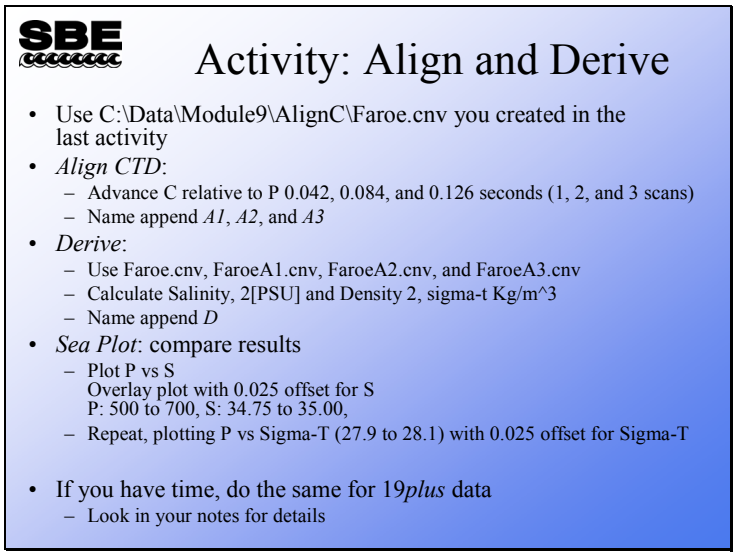
A note about sensor alignment in the 911*plus*: We mentioned earlier that the 11*plus* Deck Unit performs an automatic alignment of T and C. However, in old versions of the 11*plus*, the automatic alignment was done only on the output from the primary T and C sensors; for secondary sensors we must do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

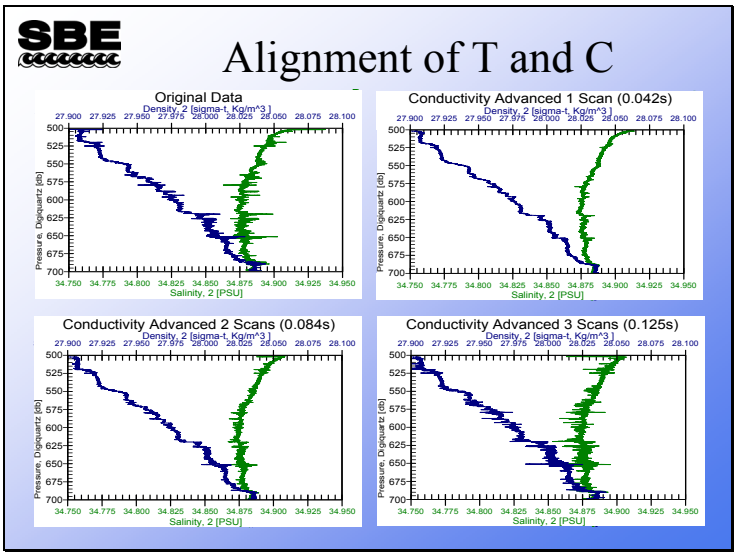
- FaroeD.cnv… Original data with salinity and density derived
- FaroeA1D.cnv… FaroeD.cnv with C advanced 1 scan = 0.042 seconds, with salinity and density derived
- FaroeA2D.cnv… FaroeD.cnv with C advanced 2 scans = 0.084 seconds, with salinity and density derived
- FaroeA3D.cnv… FaroeD.cnv with C advanced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

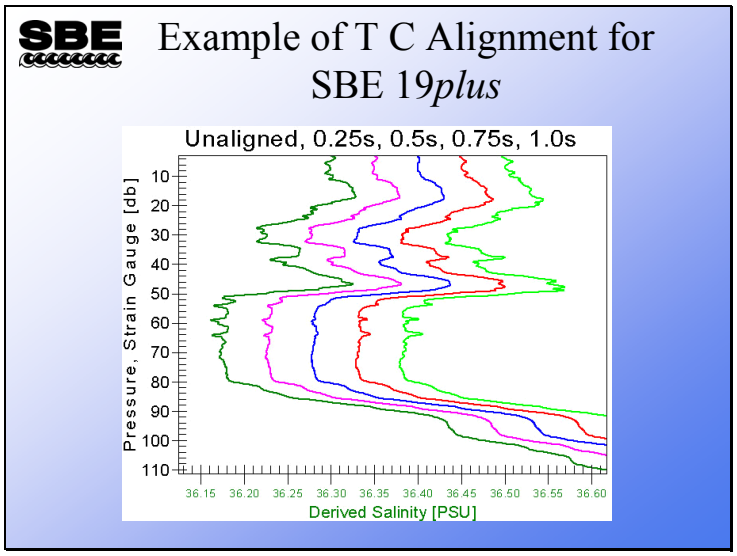
- First, filter the temperature and conductivity channels to match the sensor response, using the Filter module. On the *Data Setup* tab, set Low pass filter A to a time constant of 0.5 seconds. Click *Specify Filters…* and select *none* for pressure and *Low pass filter A* for temperature and conductivity.
- 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*)



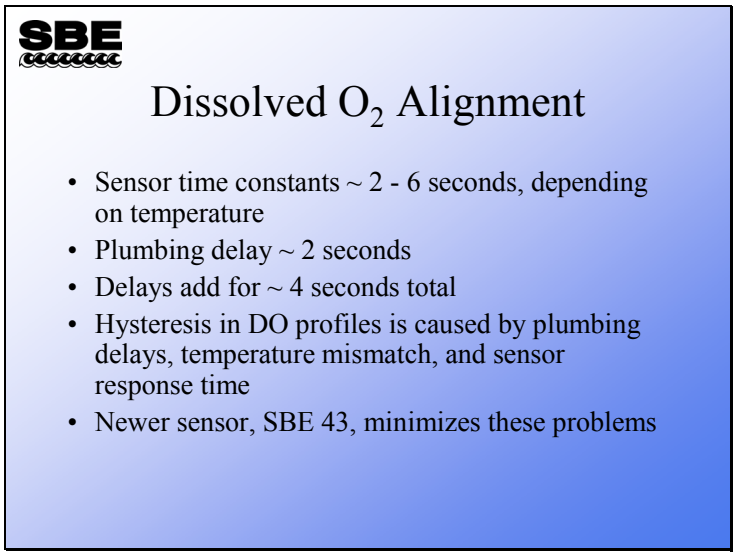
This is from the Faroe data set. The data on the upper left is unaligned, raw data. The upper right has the conductivity channel advanced relative to pressure 0.42 seconds (1 scan); spiking shows considerable improvement. The plot on the lower left has conductivity advanced 0.084 seconds (2 scans) and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



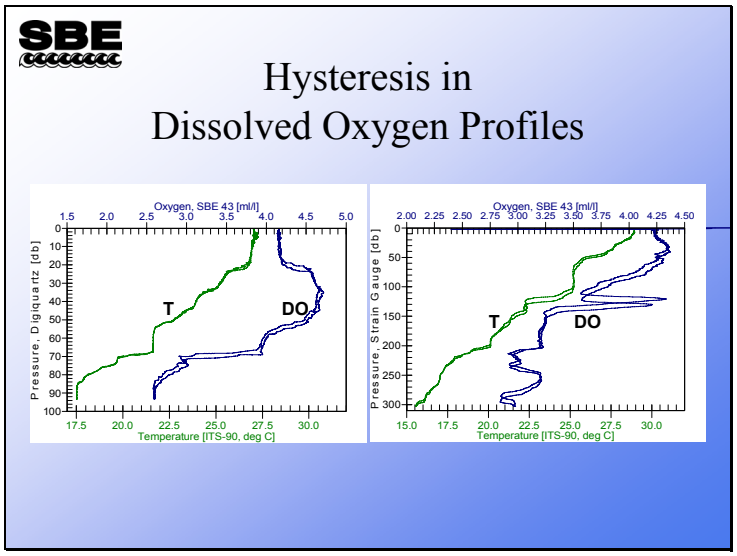
This is from the extra credit data set. The right most trace is the original unaligned data and the others, from left to right, are aligned from 1 to 4 scans. The optimal alignment value may lie between 0.25 and 0.5 seconds; it is left for the reader to experiment and find it.

Removing Misalignment in Dissolved Oxygen



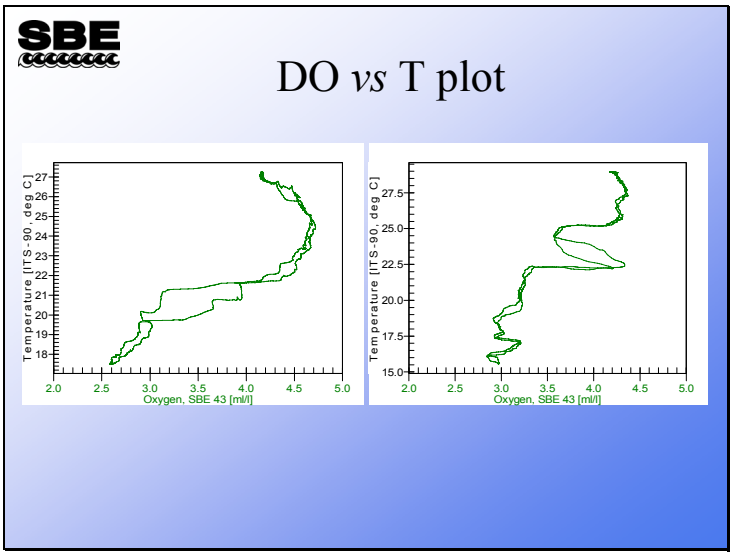
Aligning oxygen current and temperature in relation to pressure can improve hysteresis in dissolved oxygen profiles. The SBE 43 has a faster time constant and shows improvement in hysteresis over the Beckman- or YSI-type of sensor.

Removing Misalignment in Dissolved Oxygen (*continued*)



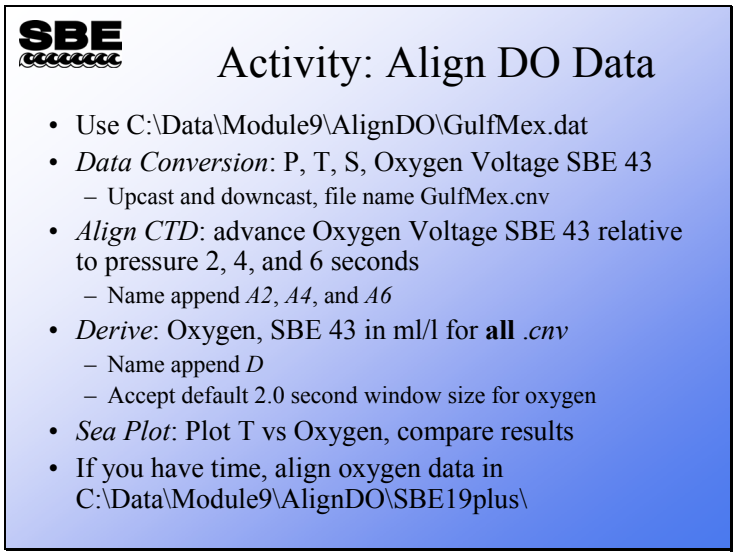
While hysteresis is easily observed in pressure *vs*. oxygen profiles, it is also easy to confuse hydrographic phenomenon with hysteresis. The plot on the right shows hysteresis in both temperature and oxygen; the peak in oxygen has a sharp gradient in temperature associated with it. The cast was taken 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.

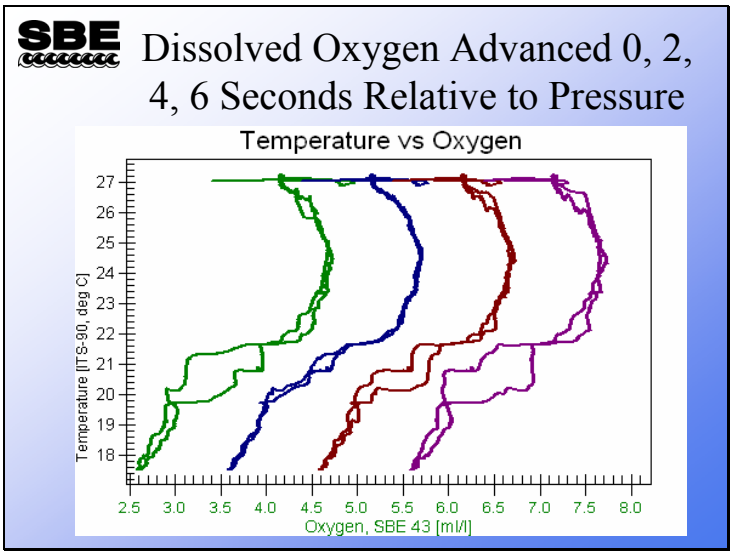
Activity



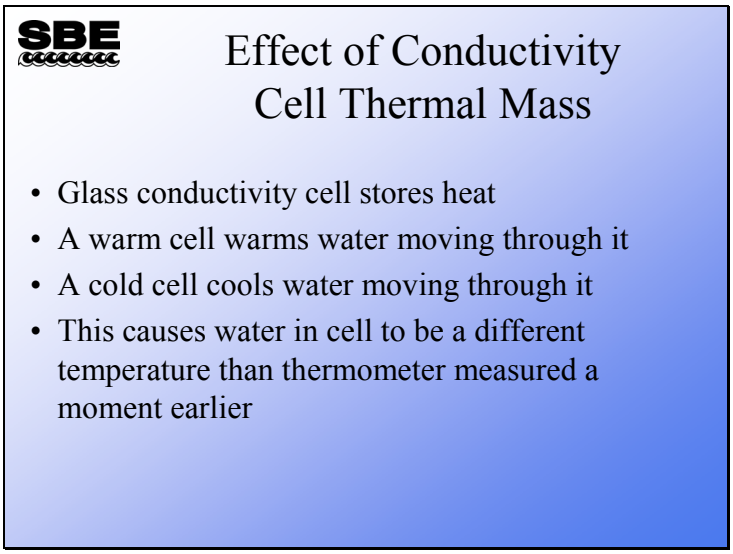
You should end up with the following files:

- 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*)

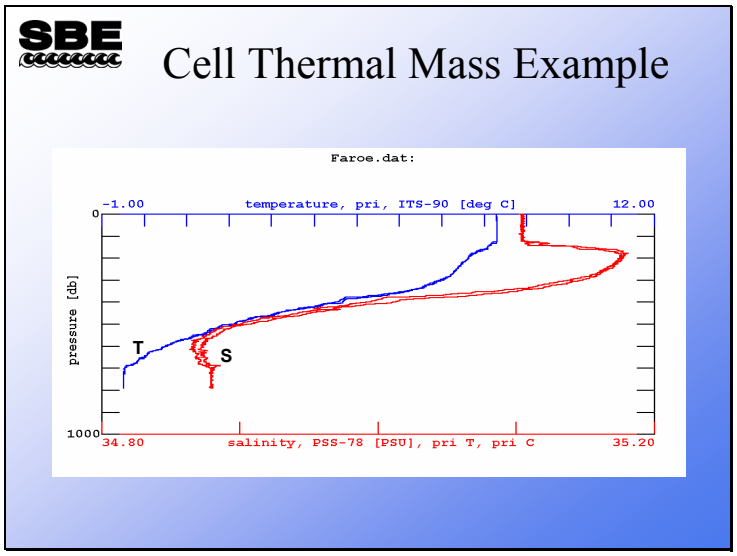


Conductivity Cell Thermal Mass



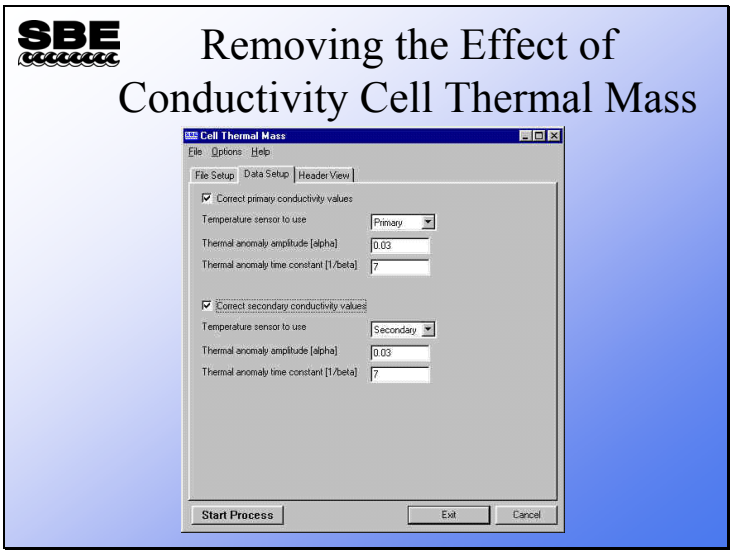
The conductivity measurement has temperature dependence. The conductivity cell itself is constructed of glass and plastic, and as such has a thermal mass. When the cell goes from warm water into cold, the water that passes through the cell is slightly warmed as it transits the cell. Conversely, when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

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

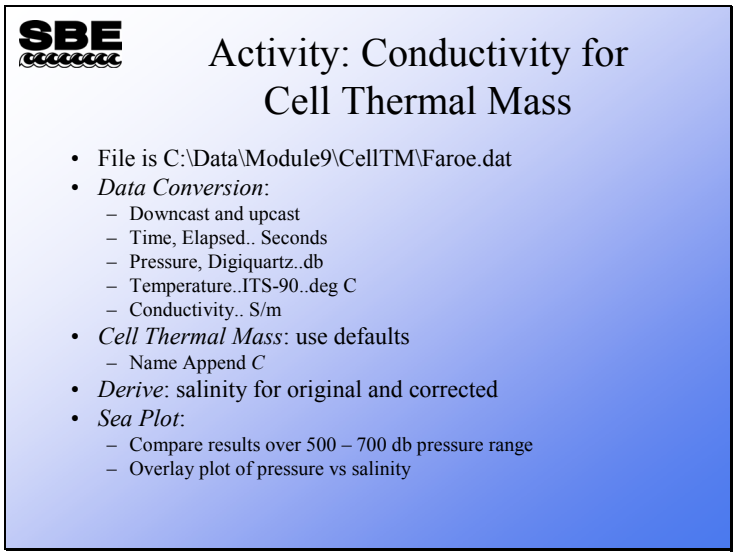
dt = temperature - previous temperature

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

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

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

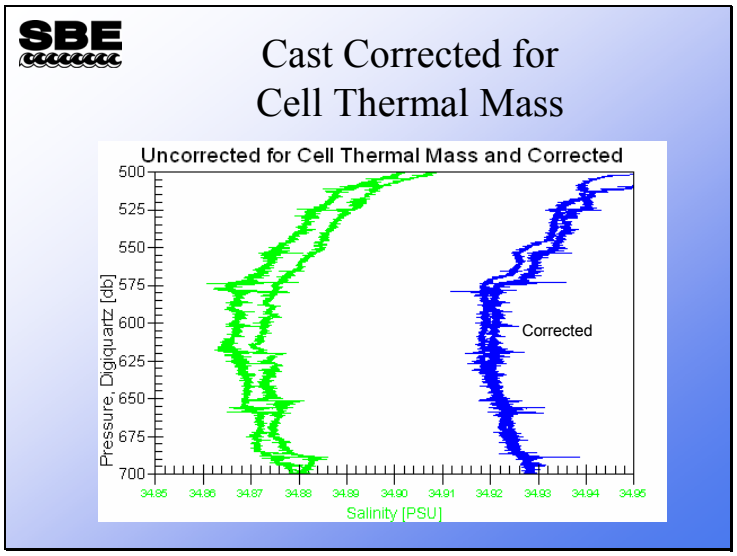
Activity



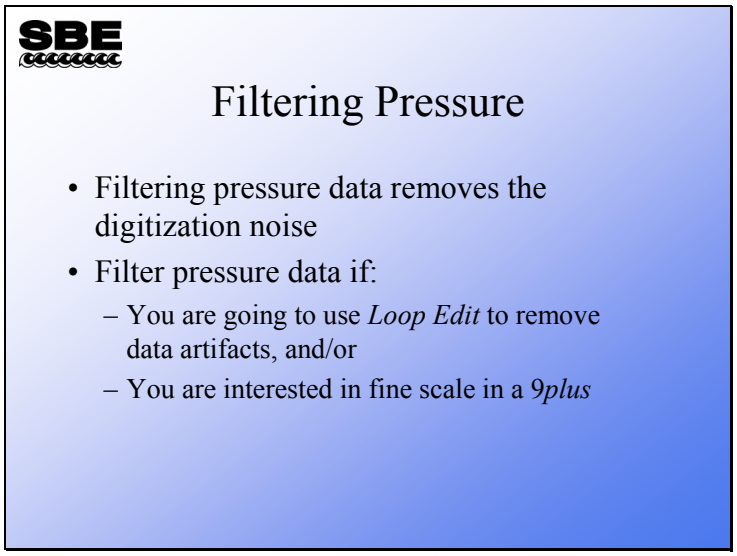
You should have files named:

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

Activity (*continued*)

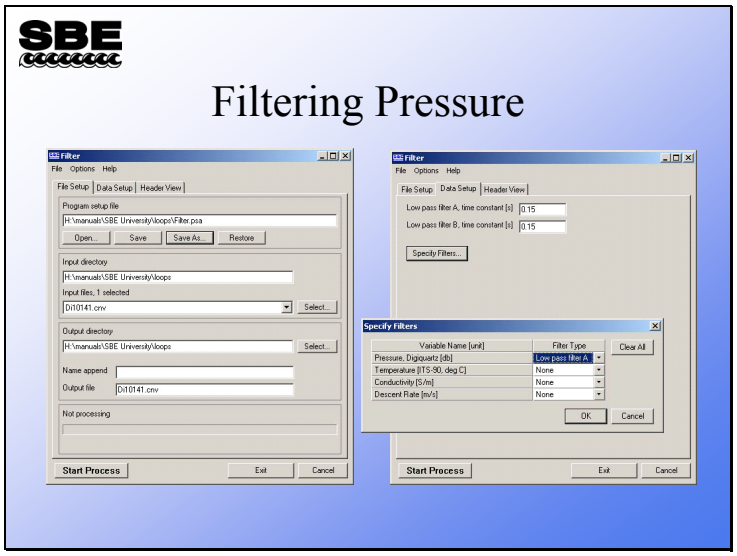


Filtering Pressure to Remove Digitization Effects

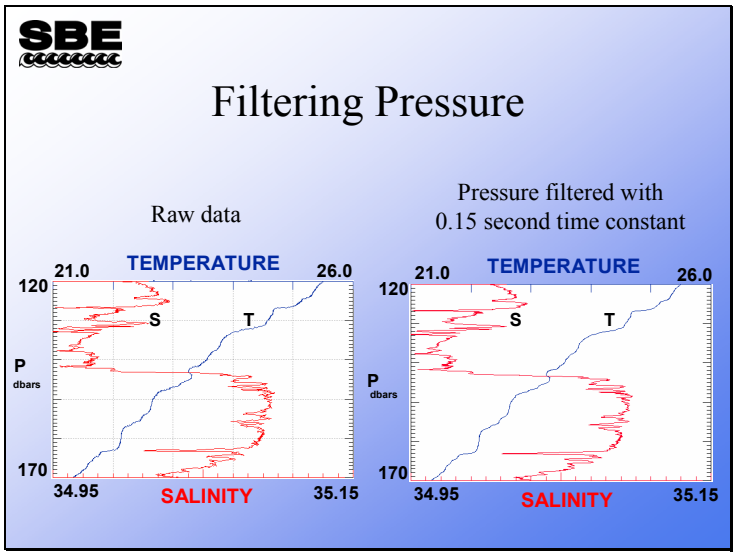


In measuring the pressure sensor signal, there is a digitization error that may be removed by filtering the signal with a low-pass filter. This has the effect of improving the resolution of the pressure signal by smoothing the digitization jitter.

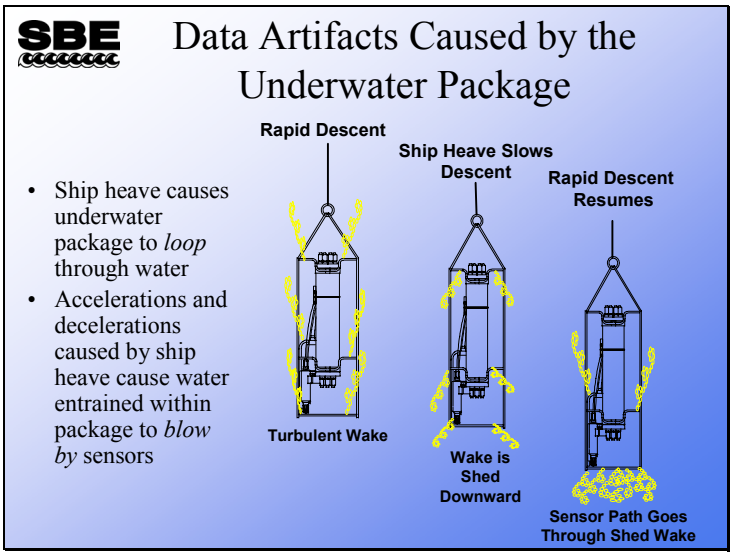
Filtering Pressure to Remove Digitization Effects (*continued*)



Filtering Pressure to Remove Digitization Effects (*continued*)



Data Artifacts Induced by Ship Heave

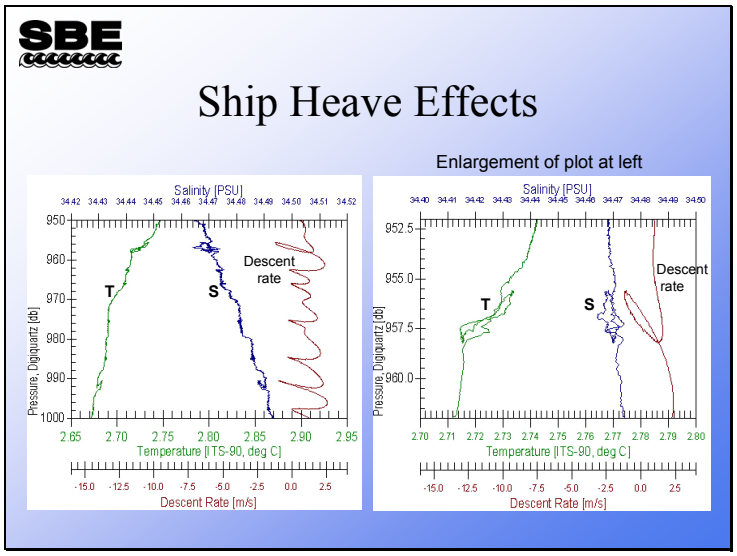


Ship heave is the rocking motion of the ship. Most CTD deployments are made with a small boom or an A-frame that leans out from the ship, giving some distance between the sea cable and the side of the ship. Ship rocking has the effect of pulling up on the sea cable when the ship rocks in one direction 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.

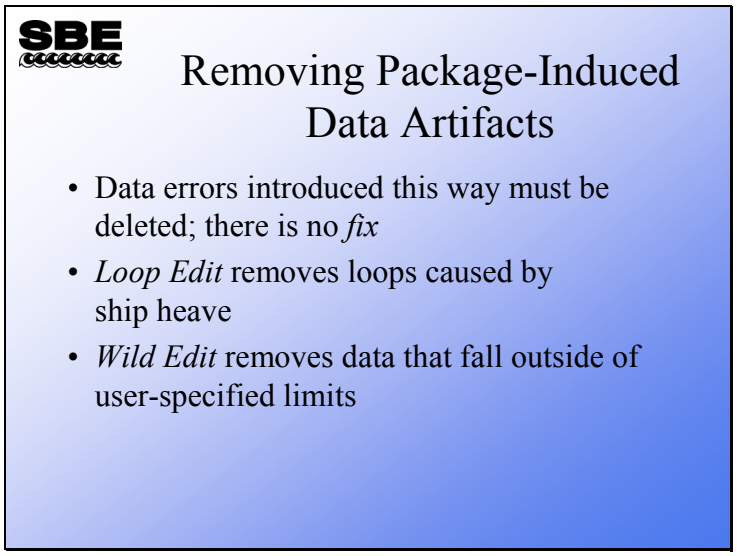
Further, in cases of radical ship heave, the instrument package can have a trajectory through the water column that describes loops. It goes without saying that this sort of behavior causes sampling errors.

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

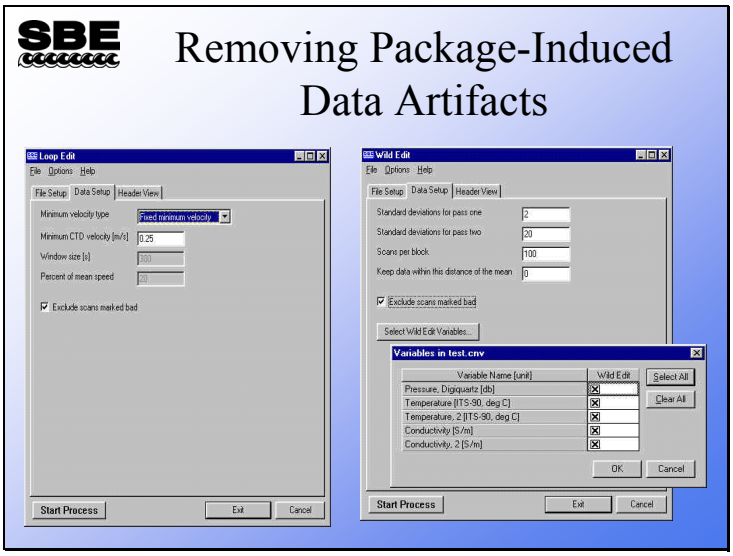


The error caused by ship heave comes from the instrument package disturbing the water that it is trying to sample. Because of this, there is no numerical solution for the problem. SBE Data Processing has two editing modules that remove the offending data. As winch technology improves, we can expect to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

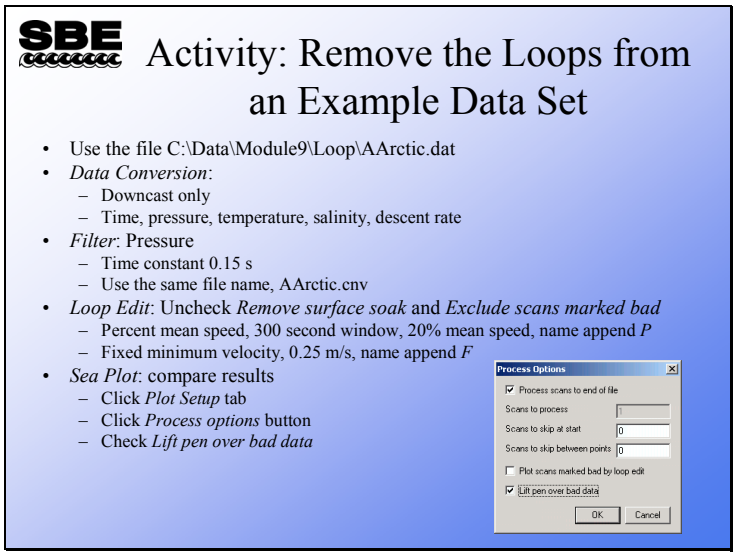
Loop Edit marks data collected when the CTD loops through the water or decelerates sharply. *Wild Edit* marks data that falls outside of user-specified limits, given as standard deviations of a window of data.

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

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



Activity



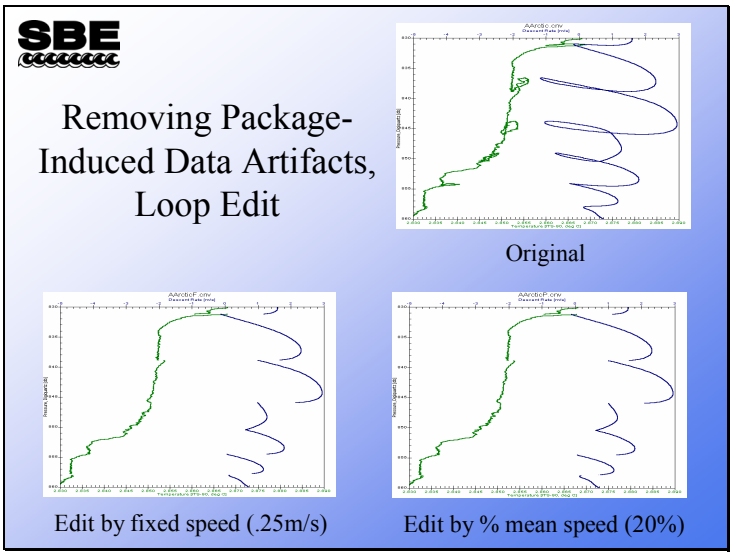
You should have the following files after processing AArctic.cnv in Loop Edit:

- 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:

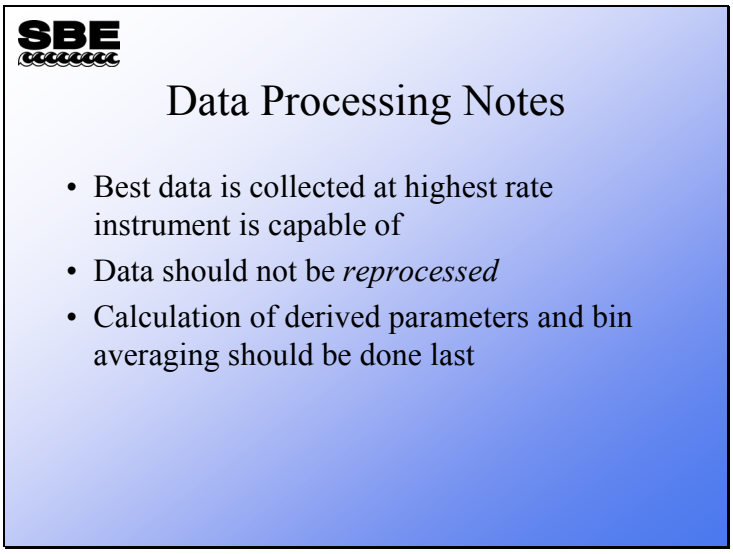
- Pressure: 830 to 860 decibars
- Temperature: 2.83 to 2.89 °C
- Descent rate: -5 to 3 m/sec

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



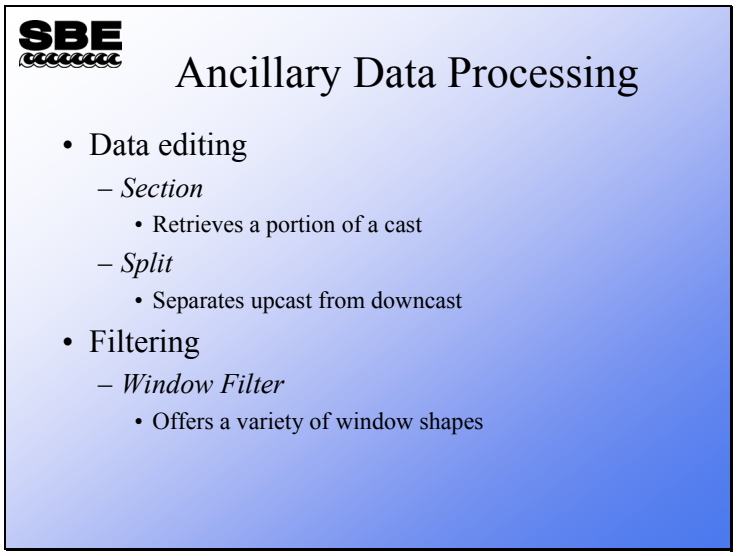
Here is the example of loopy data that we showed earlier. The bottom two plots have been edited by the two means available. Both plots show very similar results. The bottom left plot is made by editing out data that drop below a fixed speed, in this case 0.25m/s. The bottom right plot is made by editing 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

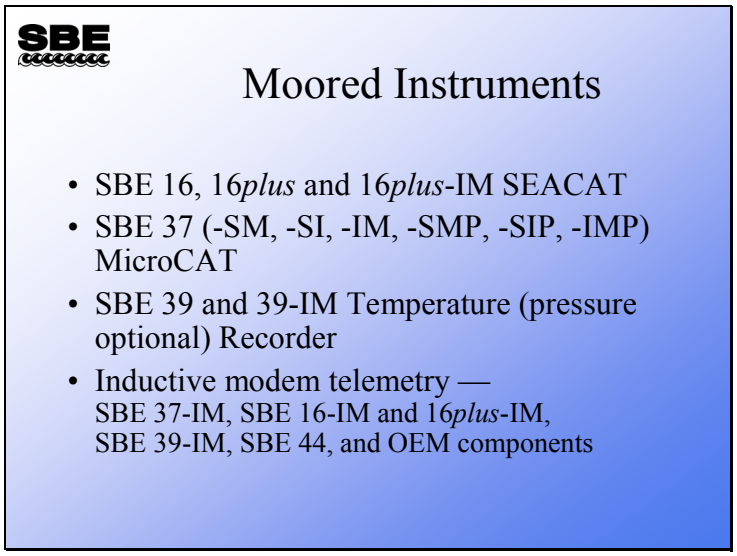


In addition to the data processing modules and procedures we have talked about, there are other modules available. You can clip out part of your data with *Section*, and separate your data into upcasts and downcasts with *Split*. And, there is a window filtering module with various shaped windows.

Module 10

Moored Instruments

Overview

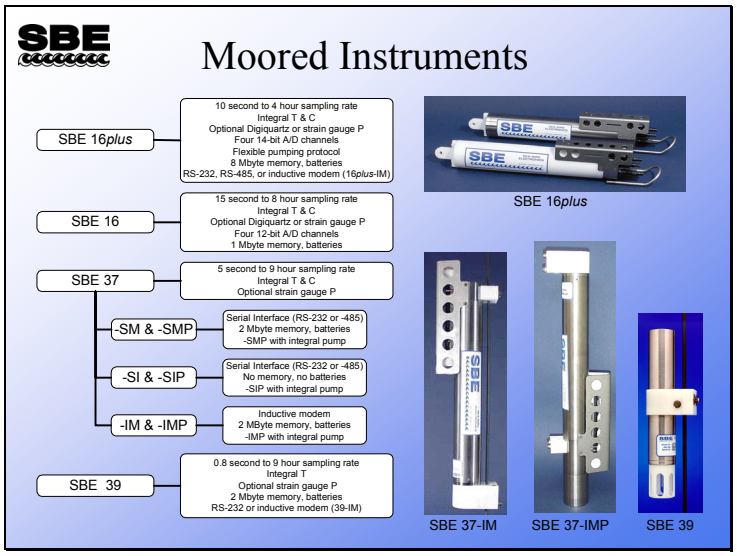


In this module we will present Sea-Bird instrumentation intended for mooring.
The SBE 16 family provides power and A/D inputs for auxiliary sensors.
The MicroCAT family is smaller and less expensive, but does not have power for external sensors nor auxiliary A/D inputs, while the SBE 39 family has only temperature and pressure. As an accessory to our moored instruments, Sea-Bird offers inductive telemetry for mooring. This technology allows communication with moored instruments in real-time without cable breakouts. The SBE 44 is a stand-alone modem meant for interfacing other manufacturer's instrumentation to the inductive mooring string.

When we complete this module you should:

- Be aware of the instrument platforms available for moored applications
- Understand the means of telemetering real-time data from the mooring to the land-based receiving station

Introduction to SBE 16, 16*plus*, 37, and 39



The SBE 16 and 16*plus* are moored versions of the SBE 19 and 19*plus*. The 16*plus* is actually a 19*plus* in moored mode, with optional pressure sensor. The 16 and 16*plus* have the capability to power external sensors and log analog A/D data from them. This is the instrument of choice if you require more data than C, T, and P. The 16*plus* is available with serial interface (RS-232 or RS-485) or inductive modem interface (16*plus*-IM).

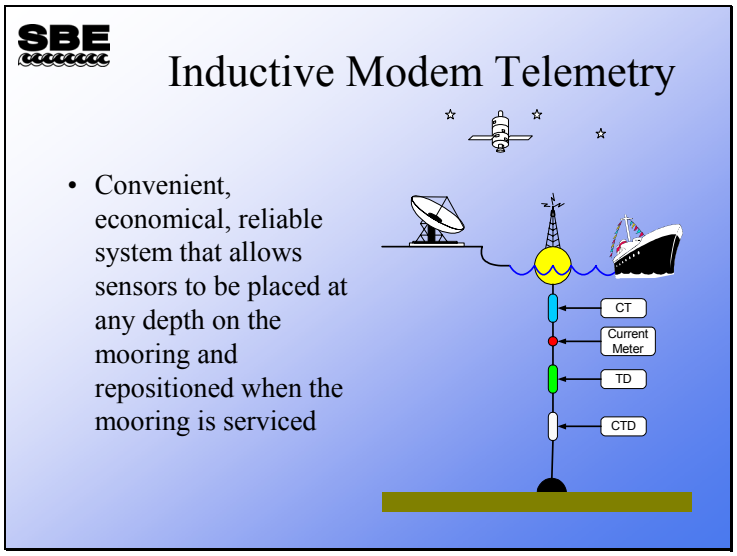
Like the 16 and 16*plus*, the MicroCAT has integral T and C sensors, and may also be equipped with a pressure sensor. The MicroCAT comes in three main types:

- The SM has memory, batteries, and a serial interface (RS-232 or RS-485). It is meant for moorings that do not require communication with the surface during deployment.
- The SI has no memory and no batteries, but does have a serial interface (RS-232 or RS-485). It is intended for ROVs, submarines, etc. as a companion for instruments requiring T and C, such as acoustic Doppler profilers or optical instruments.
- The IM has memory, batteries, and an inductive modem for communications in real-time with the surface.

All three types of MicroCAT are available with an integral pump (SMP, SIP, and IMP).

The SBE 39 is a temperature recorder, and may also be equipped with a pressure sensor. An example of its use is mounted on bottom trawls to measure bottom depth, time on bottom, and temperature. The SBE 39 is available with serial interface (RS-232) or inductive modem interface (39-IM).

Inductive Modem Telemetry

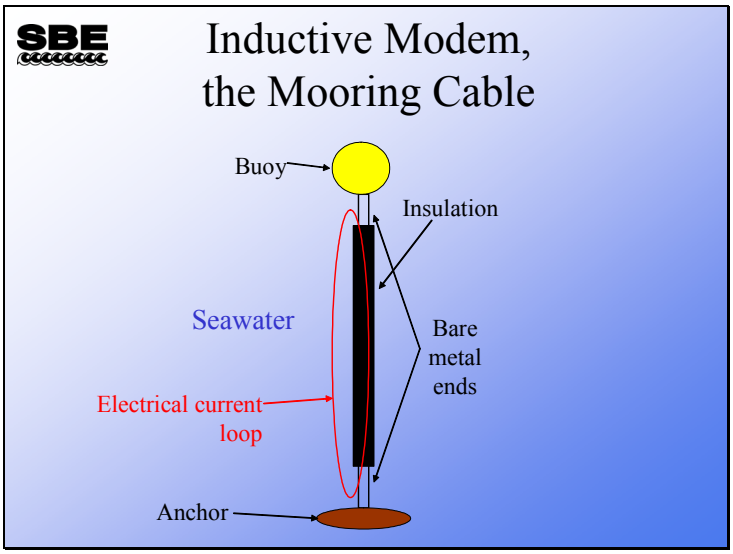


An inductive modem uses electrical current loops to transmit information. Recall from physics class, electrical current flowing in a wire loop induces current to flow in a loop that passes through it. You can think of these loops as links in a chain. The first loop is in the surface buoy. The second loop is formed by the mooring cable and the seawater. The third loop is at the instrument, underwater. Because all coupling is done in loops, no cable breakouts are required.

The communications link is one way only, meaning that if the surface modem is transmitting to the remote instruments, then the remote instruments must all be listening. Conversely, if one of the remote instruments is transmitting, then the surface modem must be listening. To achieve this, all instruments have a unique two-digit address from 00 to 99.

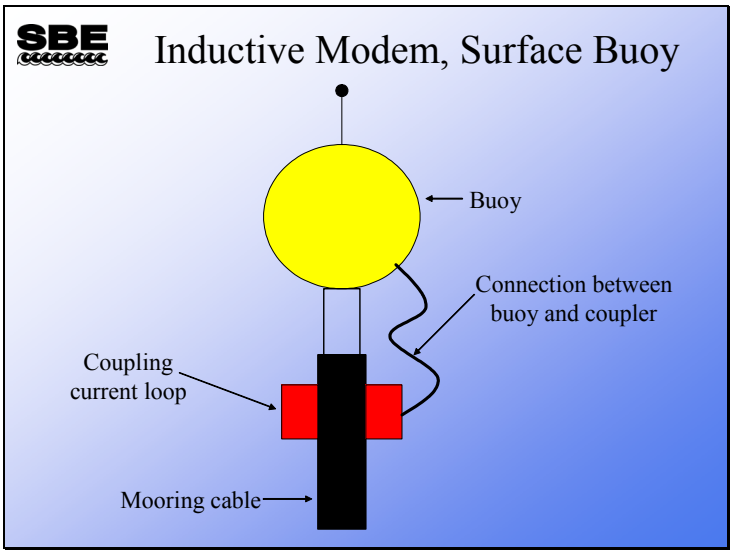
The electrical current carries an AC signal that is phase-shift-keyed. Digital data is encoded by the transmitting modem into an AC signal that is impressed on the current loop, and it is received and decoded by the remote modem's receiver.

Inductive Modem Telemetry (*continued*)



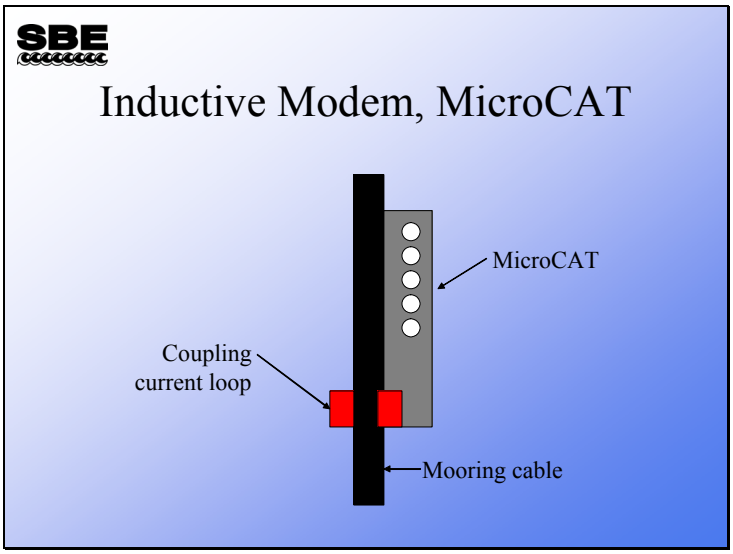
The first current loop is made by the mooring cable itself and seawater. The cable is bare metal on the top and bottom and insulated in the middle.

Inductive Modem Telemetry (*continued*)



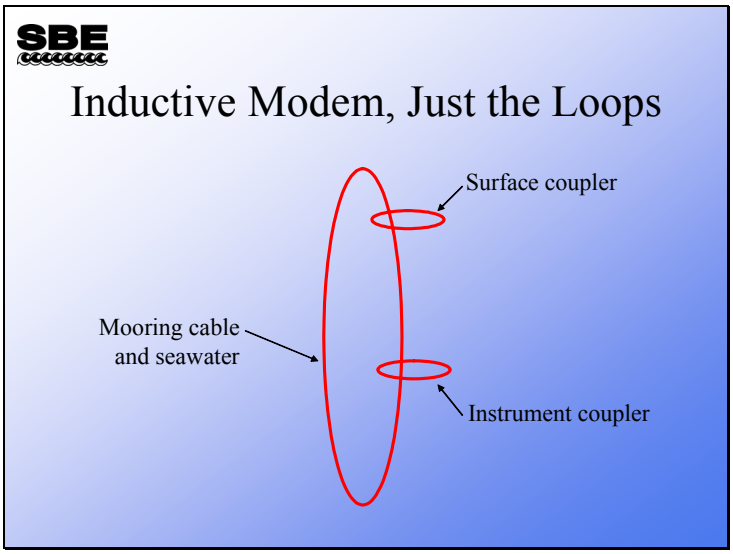
The second current loop is made around the mooring cable. The coupler is a ferrite donut. Ferrite is the stuff that magnetic tape is made from. The electrical current that flows around the coupler induces a current that flows through the mooring cable and the seawater. Thus, the modem signal is transmitted by the surface buoy into its coupler, and the coupler induces a current in the seawater and mooring cable.

Inductive Modem Telemetry (*continued*)



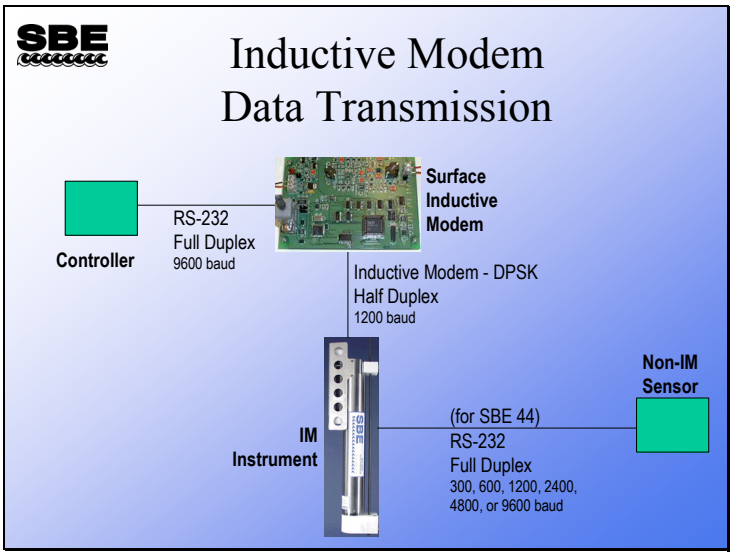
The last loop is at the remote instrument. It has a coupler just like the surface buoy. The current that the surface buoy has induced in the seawater mooring cable loop in turn induces a current in the remote instrument's coupler. The modem in the remote instrument receives and decodes the signal. If the information contained in the signal is addressed to the remote instrument it behaves accordingly, e.g., transmitting a data scan or a status report.

Inductive Modem Telemetry (*continued*)



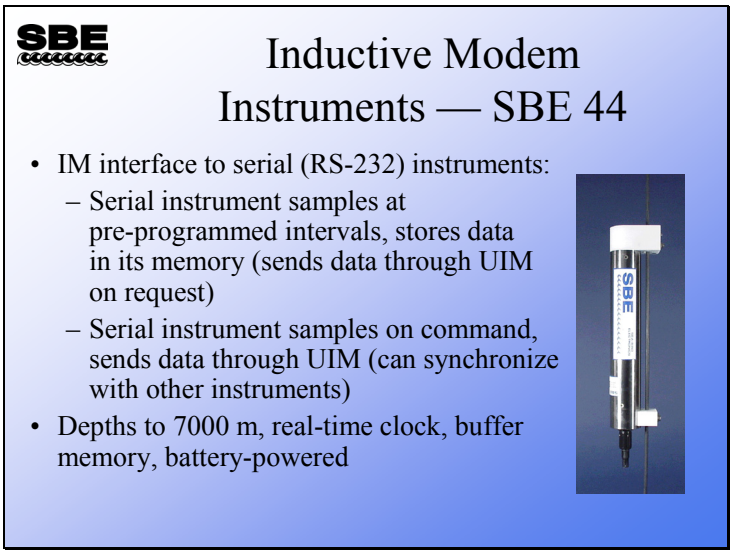
Here is a very simple view of the communication links. Note that there can be up to 100 instrument couplers on the mooring cable – seawater loop.

Inductive Modem Telemetry (*continued*)



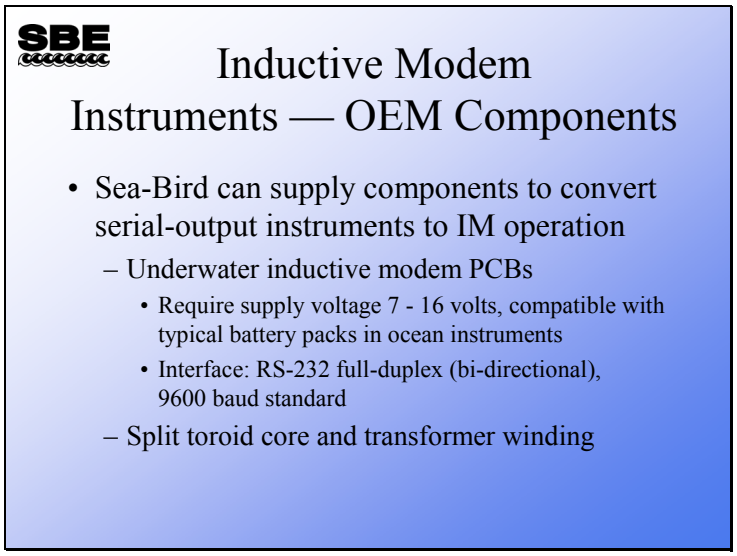
Here are all the players in inductive modem data transmission. The controller is user-supplied and should be able to switch power to the surface inductive modem (SIM). The inductive modem DPSK is via the mooring cable. If you want to use sensors with serial data output made by another manufacturer, the SBE 44 is a stand-alone inductive modem supporting common baud rates with buffering sufficient for most applications.

Inductive Modem Instruments

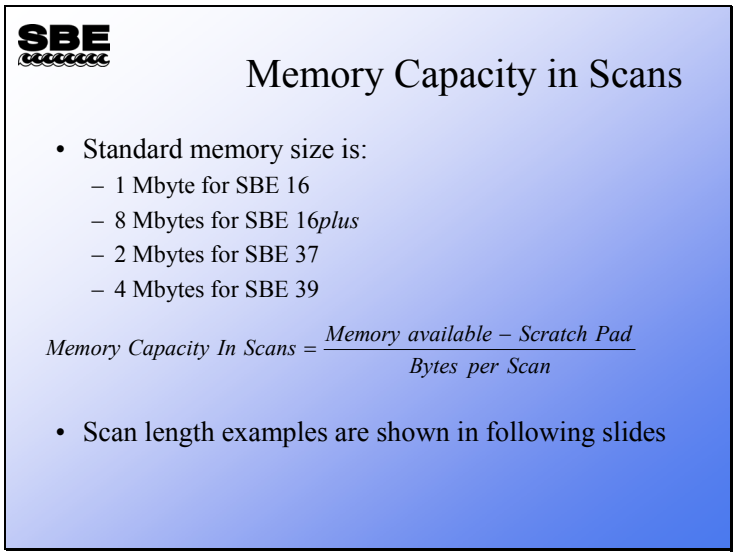


The SBE 44 is meant to allow the use of instruments that have a serial interface and the capability to sample on demand to be used with an inductive telemetry mooring. The SBE 44 has an internal 9 volt, 7.2 amp-hour battery and can provide power to the external device. Alternatively, the external device can provide power to the 44. The inductive link operates at 1200 baud. This restricts the data rate of the external instrument; however the SBE 44 has data buffers that allow the external instrument to transmit small amounts of data at a higher rate.

Inductive Modem Instruments (*continued*)

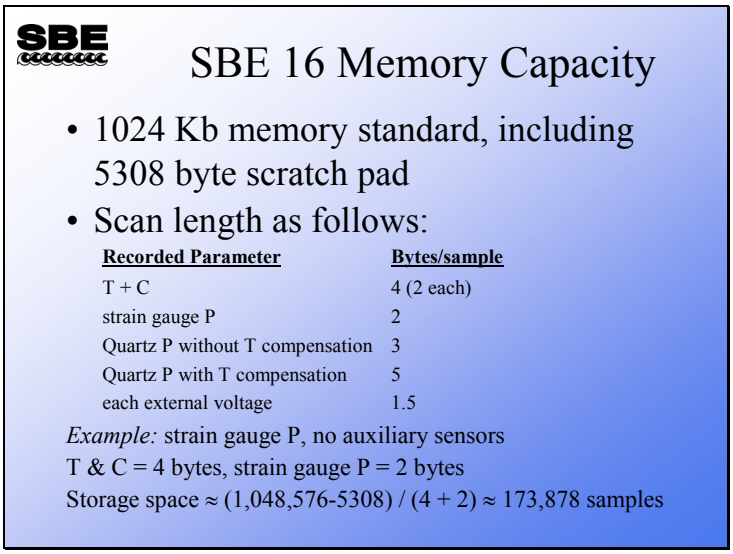


Memory Capacity



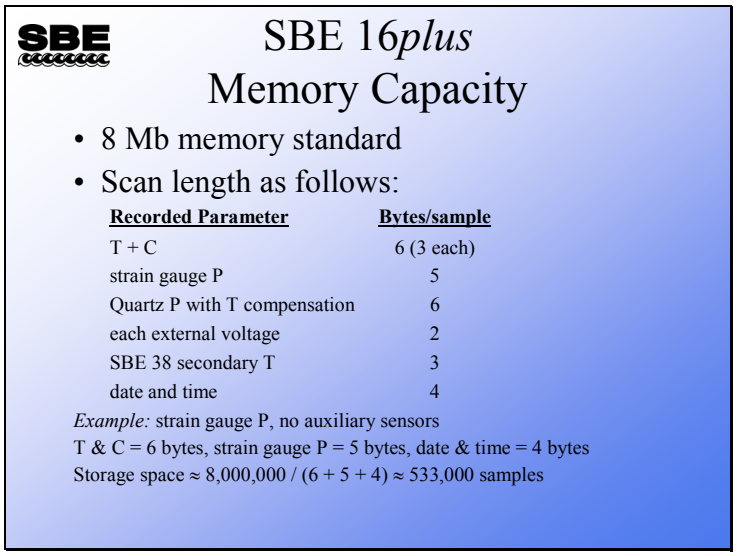
Memory capacity calculations are basically the same as seen for profiling instruments. Refer to Module 1, page 9 for an overview of this calculation; examples for specific instruments are on the following pages.

Memory Capacity: SBE 16



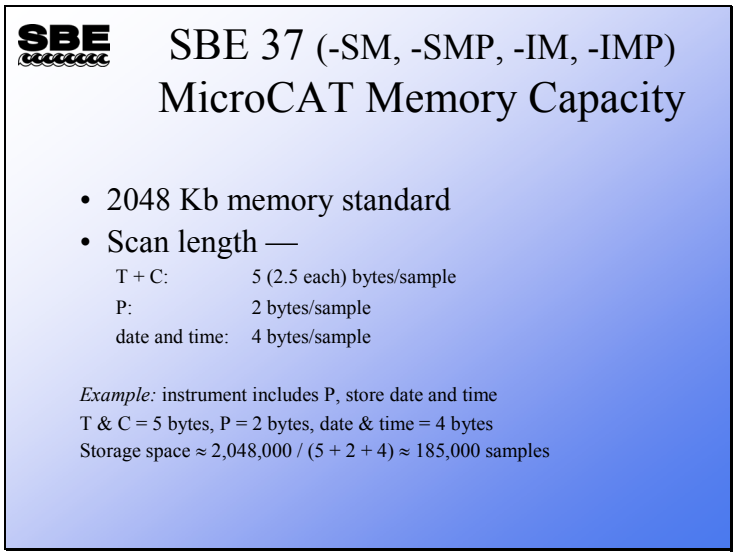
The SBE 16 has battery backed-up semiconductor memory of 1 Mbyte. Actual capacity in scans depends on how the instrument is configured.

Memory Capacity: SBE 16*plus*

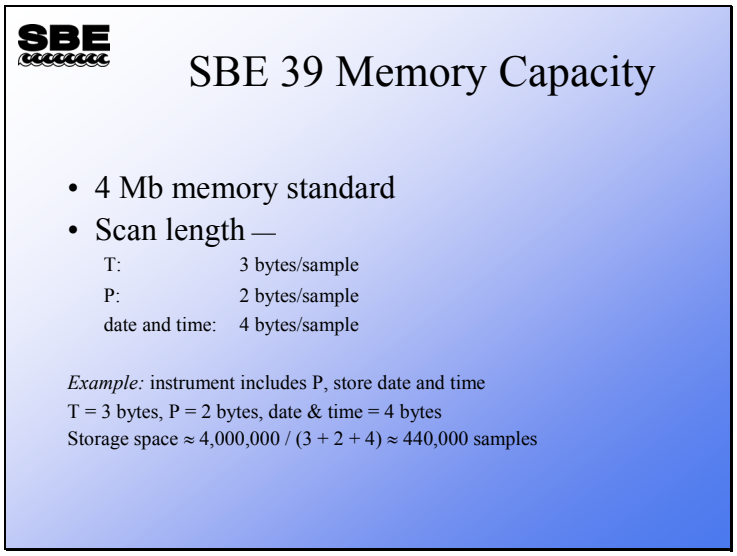


The SBE 16*plus* has considerably more memory than the 16, with 8 Mbytes of non-volatile flash memory. Again, memory capacity depends on the configuration of the instrument.

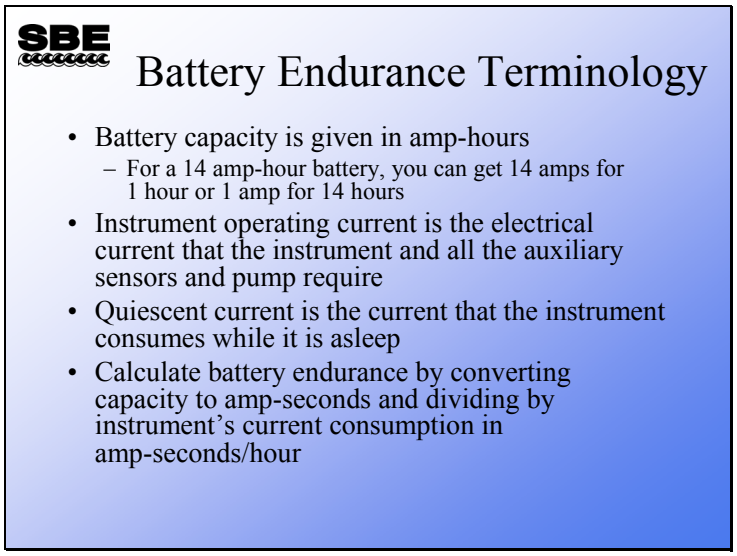
Memory Capacity: SBE 37 MicroCAT



Memory Capacity: SBE 39



Battery Endurance

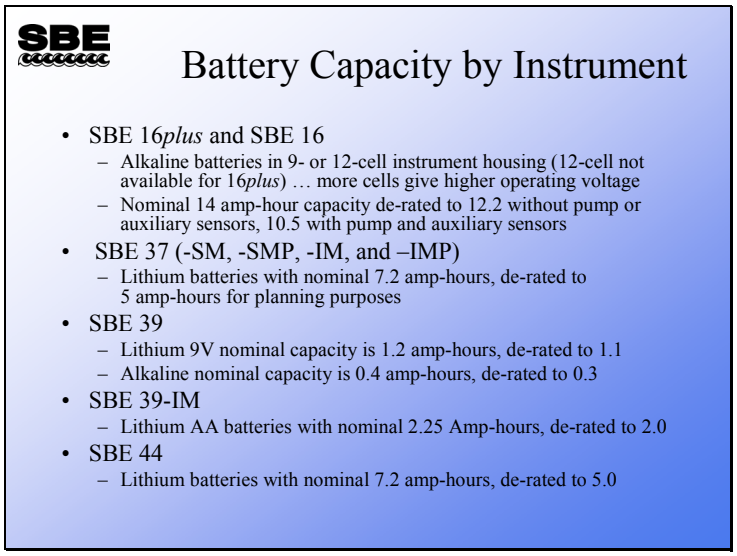


Battery endurance is a topic of great interest to those who work with moored instruments. However, estimating battery endurance is a very difficult to do accurately. Battery manufacturers specify the amount of energy contained in a battery in terms of ampere hours. This is the amount of current that the battery can supply for a given length of time. If a small amount of current, 100 milliamps for example, is drawn from the battery, it will last many hours (years). Conversely if a large current is drawn, 1 amp for example, the battery will last for few hours.

Calculating battery endurance requires summing the amount of current drawn by the instrument and its auxiliary sensors for the length of time they are operating. In addition, the quiescent current of the main instrument must be included. The quiescent current is that drawn by the instrument while it is sleeping, and is required for operation of the clock and the circuits that monitor the communications lines, so that when you attempt to communicate with the instrument it awakens and responds.

For instruments that use alkaline batteries, Sea-Bird uses Duracell brand alkaline batteries exclusively; all our examples for alkaline batteries will be based on these.

Battery Capacity by Instrument

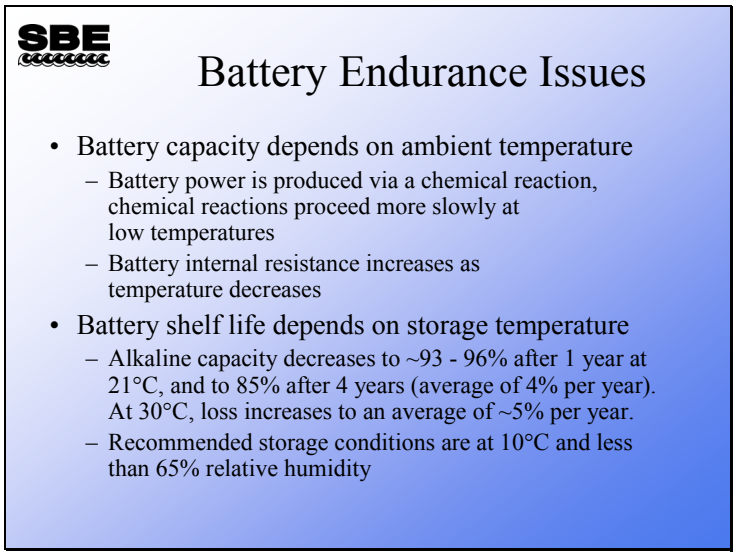


Sea-Bird offers different types of batteries depending on the type of instrument.

- The SBE 16*plus* is normally supplied with alkaline batteries; however a lithium battery pack *kit* may be supplied at the user's request (these lithium batteries are not supplied by Sea-Bird).
- The SBE 37 and 44 come with lithium batteries only.
- The end user may choose lithium or alkaline batteries for the SBE 39.
- The SBE 39-IM comes with AA lithium batteries only.

  Note: A few early versions of the 39-IM used the same batteries as the SBE 39.

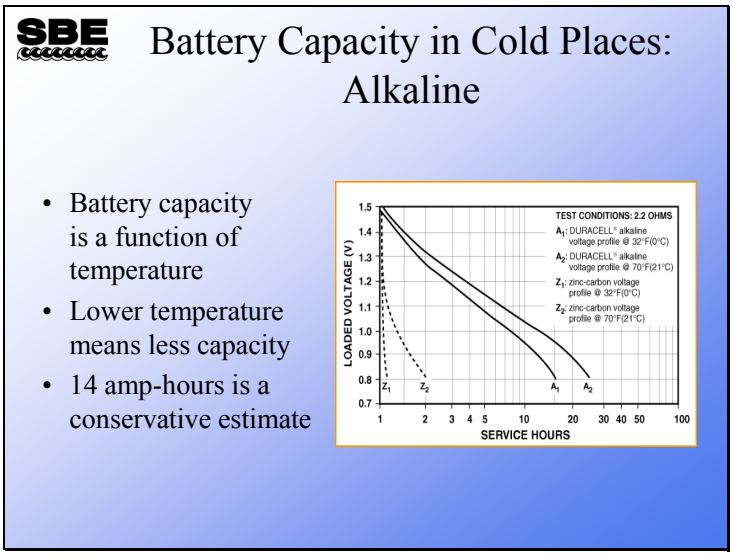
Battery Endurance Issues



As mentioned in a previous page, battery endurance is very difficult to estimate. Battery capacity depends on the temperature of their use for the reasons outlined in the slide above. In addition, batteries exhibit shelf life degradation. A battery in storage will slowly discharge at a rate that leaves about 85% capacity after 4 years in good storage conditions. Batteries stored at high temperatures will lose capacity more rapidly. Obviously, a fresh battery has the most capacity.

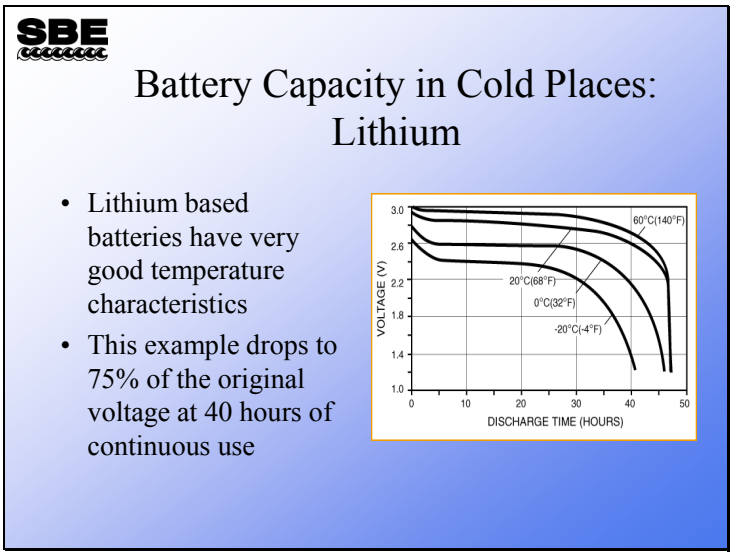
- A battery operated at high temperature will gain capacity due to a faster chemical reaction and lower internal resistance, but will lose capacity due to more rapid shelf life degradation.
- Conversely, a battery operated at low temperature will gain from better shelf life but lose due to less efficient chemical reaction and higher internal resistance.

Battery Endurance: Alkaline Battery Capacity



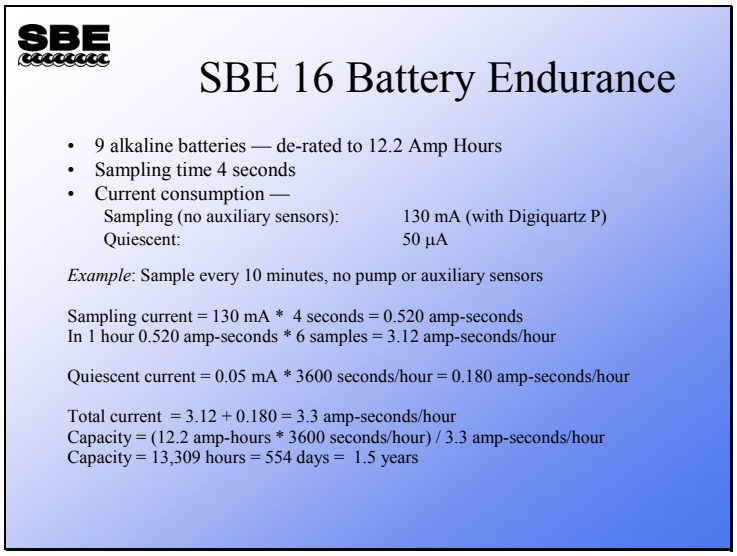
Considering the time and money involved in making a mooring, fresh batteries are a small expense. We estimate the battery life in an SBE 16 or 16*plus* assuming that it begins with 14 amp-hours of power. As you see from the plot, 14 amp-hours is a conservative estimate. At 0 °C an alkaline battery is expected to supply 0.8 volts after 15 hours of service. A standard, 9-cell battery pack starts at 13.5 volts and drops to 7.2 volts after 15 hours. Sea-Bird instruments measure the battery voltage and will not sample if the voltage is below a cut-off threshold. The value of 7.2 volts is above the cut-off for an SBE 16 and just below it for a 16*plus*.

Battery Endurance: Lithium Battery Capacity



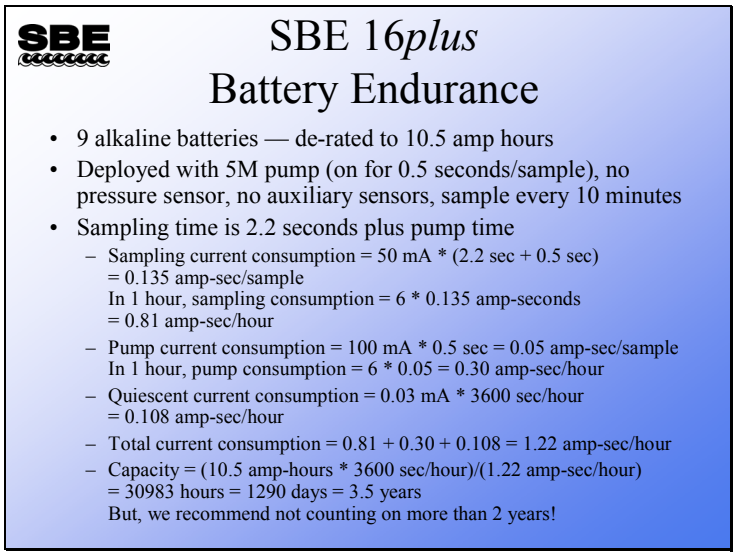
Lithium batteries offer better performance. The main drawback to using them is international shipping restrictions on lithium. For example, the battery pack used by the SBE 37 is made of 6 batteries. It is legal to ship them separately; however, once assembled into the battery pack they become illegal to ship, as they are too large a mass.

Battery Endurance: SBE 16



Recall the slide on memory endurance for the SBE 16. We can calculate that we have memory for 115,918 samples if measuring temperature, conductivity, and Digiquartz pressure, with no auxiliary sensors (115,918 = [1,048,576 – 5308] / [4 + 5]). This is enough memory for 19,319 hours of operation if sampling every 10 minutes. We will run out of battery power before we run out of memory.

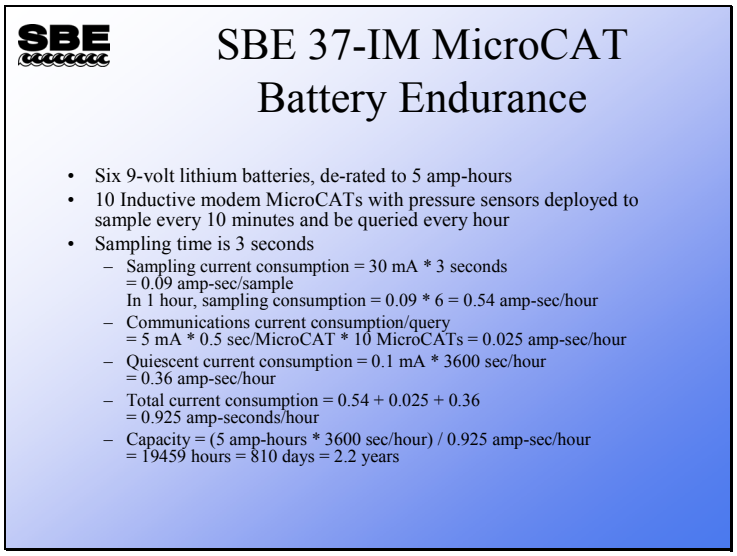
Battery Endurance: SBE 16*plus*



Recall the slide on memory endurance for the SBE 16*plus*. We can calculate that we have memory for 800,000 samples if measuring and storing only temperature, conductivity, date and time (800,000 = 8,000,000 / [6 + 4]). However, we have battery power for only 185,000 samples (≈ 30983 hours * 6 samples/hour). As with the SBE 16, we are battery-limited.

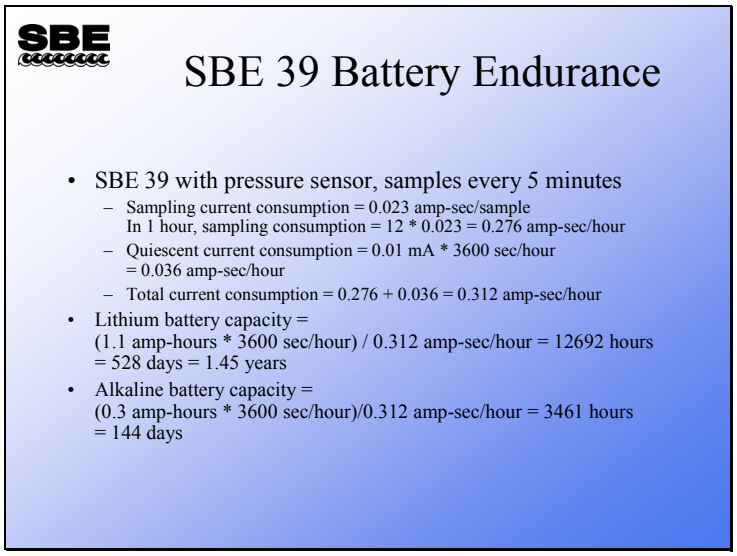
Note that battery capacity depends on operating temperature; capacity is reduced as battery temperature goes down. With profiling applications, an instrument may spend part of its time in cold water. In moored applications it is not unusual for an instrument to spend its entire deployment in cold water.

Battery Endurance: SBE 37 MicroCAT



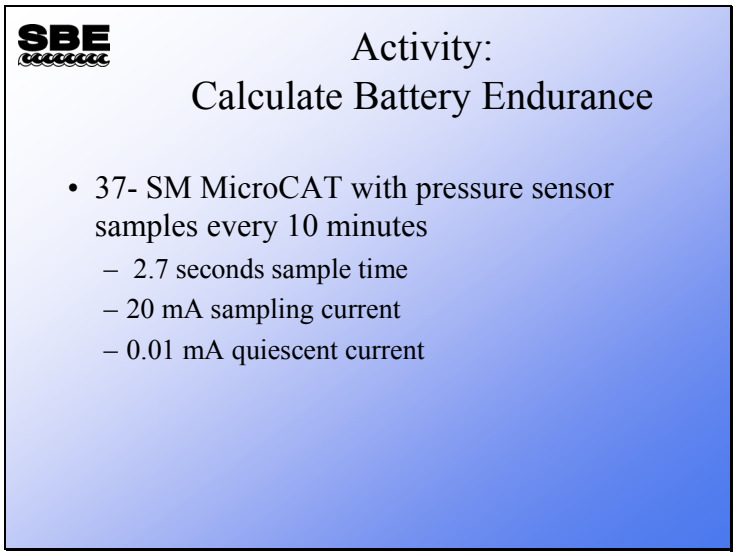
As we have come to expect, the MicroCAT has more memory than batteries.

Battery Endurance: SBE 39



Sea-Bird provides a battery endurance calculator, SBE Battery Budget Calculator, which can perform these calculations for our moored instruments. The calculator, an Excel spreadsheet, is available on the training CD as well as on our website.

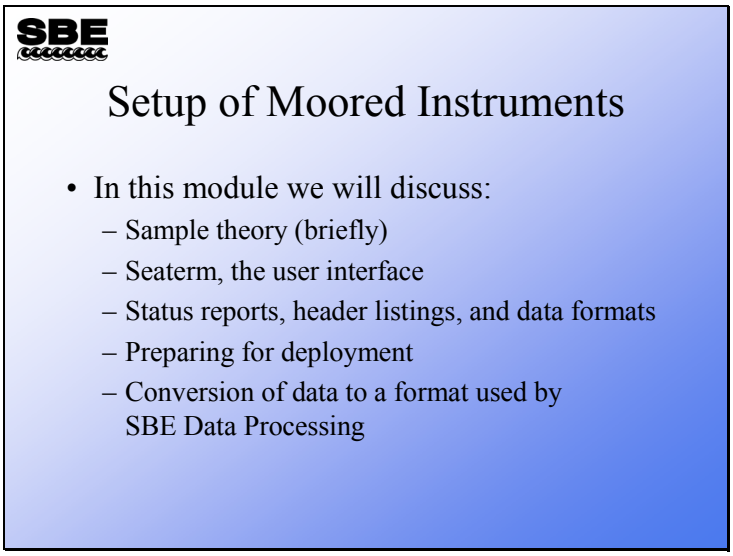
Activity


SBE
Activity:
Calculate Battery Endurance
• 37- SM MicroCAT with pressure sensor samples every 10 minutes
– 2.7 seconds sample time
– 20 mA sampling current
– 0.01 mA quiescent current

Module 11

Setup of Moored Instruments

Overview

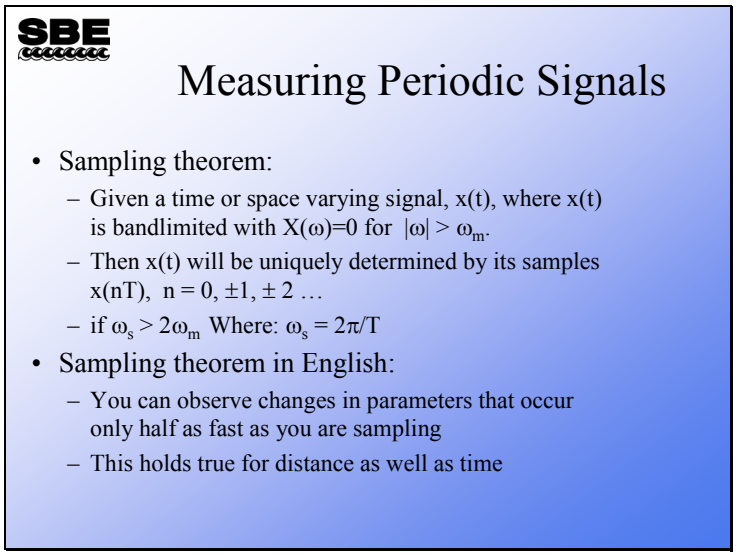


In this module we will discuss setup of moored instruments for deployment, considering sampling theory, the user interface, and instrument status reports.

By the end of this module, you should be able to:

- Understand what sort of time-scale phenomena you can observe with a given sampling rate
- Judge your instrument's readiness for deployment based on its status report
- Prepare your instrument for deployment
- Convert data from your instrument to a format that can be processed by SBE Data Processing

The Sampling Theorem



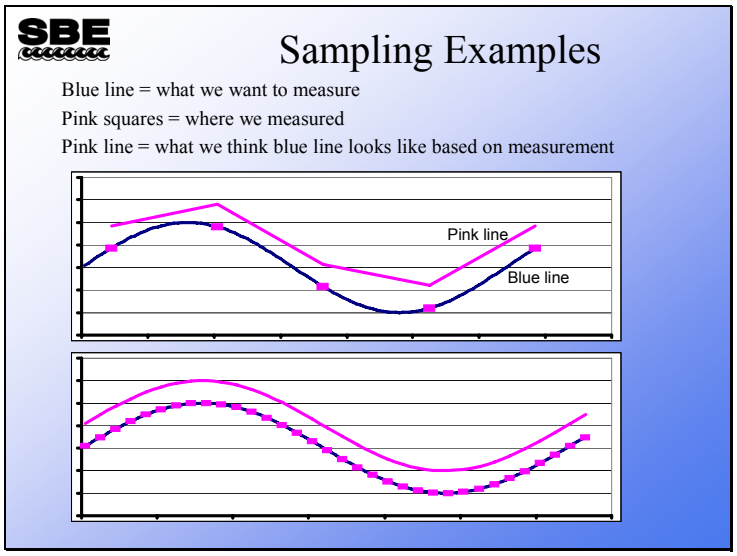
It is rather difficult to understand what this has to do with making measurements in the ocean by looking at the math.

The sampling theorem tells us how much information we can extract from a signal, given the rate at which we sample. In this case, the signal is any of the parameters we measure in the ocean. The sample rate is the rate at which the instrument makes a measurement or takes a scan.

The sampling theorem states *the highest frequency of information we can extract from a signal is half the frequency that we sample*. This means that if you sample at once an hour you can resolve signals that occur with a 2 hour period.

This holds true for distance as well as time. If we place instruments 10 meters apart on out mooring, we can resolve signals that have a length scale of 20 meters.

Sampling Theorem: Sampling Examples



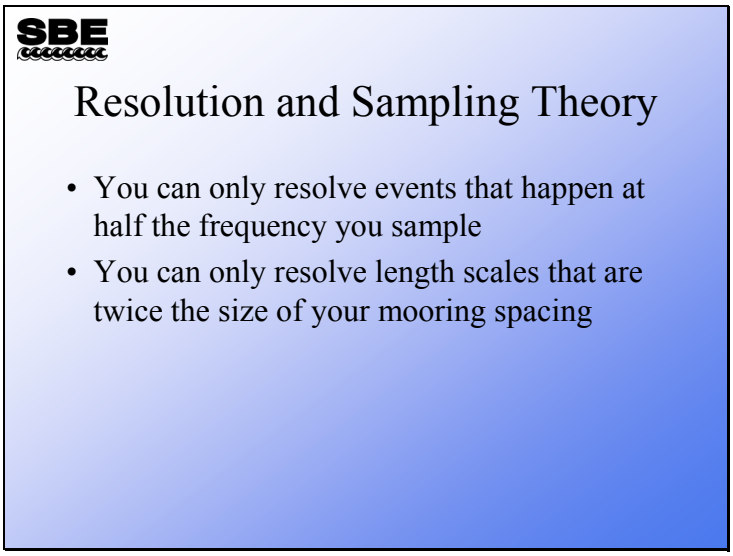
Top Illustration - Under Sampled:

Suppose we wish to measure a sine wave that has 16 cycles per hour. However, our sampling equipment is only capable of taking a measurement 5 times per hour. The upper line is our estimate of what the sine wave looks like.

Bottom Illustration - Properly Sampled:

This signal is properly sampled; the upper line is a complete representation of the lower line.

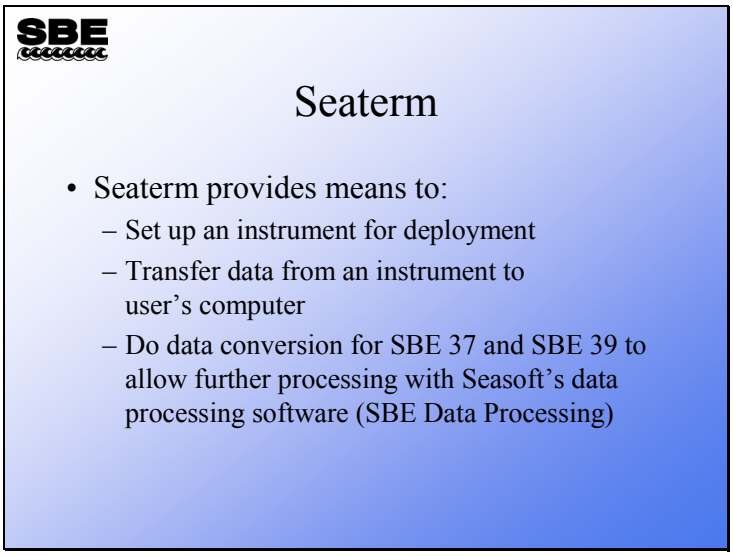
Resolution and Sampling Theory



In the profiling section of the course, you will recall we spent some time considering what sort of events or characteristics in the ocean we could expect to resolve given the sensor characteristics, sampling rates, and the lowering speed of the instrument package. The situation with moored instruments is simpler by virtue of the fact that they stay in one place (hopefully) and their sampling rates are usually slow enough that sensor characteristics are not an issue. Thus, you can resolve events that occur on time scales of 10 seconds to 18 hours given sample rates of 5 seconds to 9 hours.

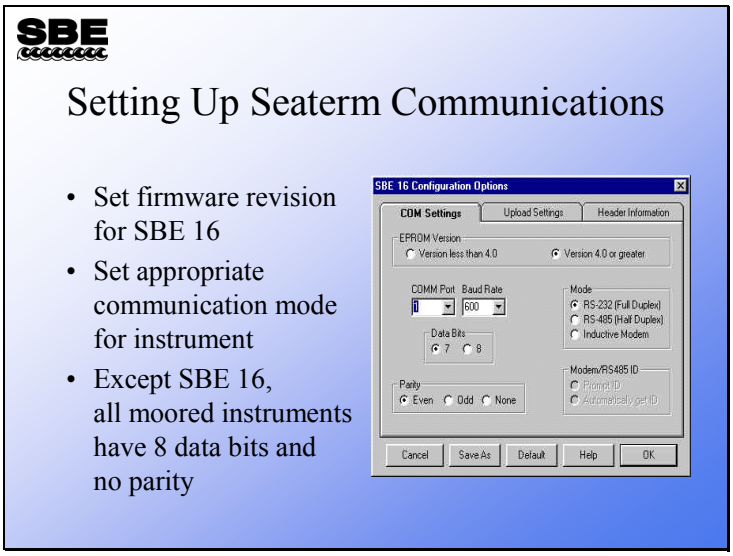
In the length domain, the characteristics you can resolve depend on the spacing of instruments on the mooring and the space between moorings. As in the time domain, you can resolve characteristics that occur on scales that are twice your spacing on the mooring.

Seaterm: User Interface



Even in moorings that use inductive telemetry, the data that is stored in the instrument is of interest. There may be occasions where the link between the surface buoy and the ground station malfunctioned, or the telemetered data may be a subset of that collected by the remote instrument. Seaterm provides the facility for data transfer and for the conversion of SBE 37 and SBE 39 data to a format that can be used by the processing programs in Seasoft.

Setting up Seaterm for Communications



For the SBE 16, older versions of firmware (EPROM version) do not support a shift to higher baud rate during data transfers. If the firmware selection is not properly set, the data transfer will fail.

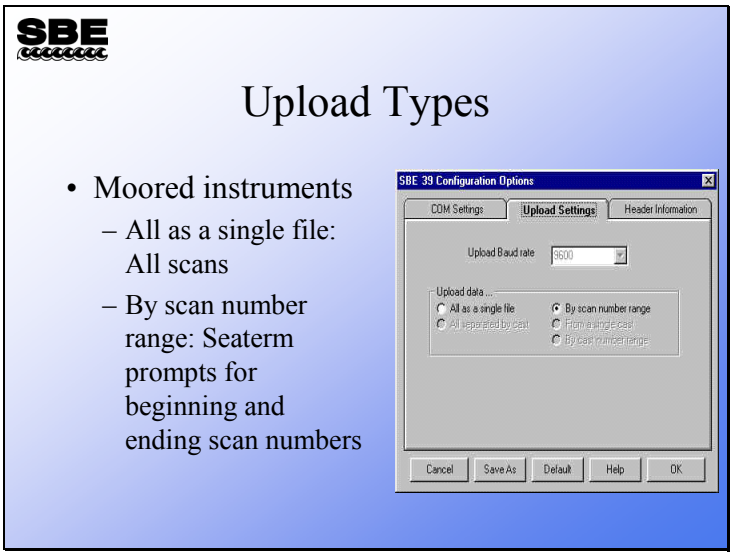
The SBE 16*plus*, 37, and 39 do not support the shift to higher baud rate for data transfer; the user sets the baud rate with the *baud*= command. Also, only 8 data bits, 1 stop bit, and no parity is used for these instruments.

Note that three different types of serial communication are supported in Seaterm:

- RS-232
- RS-485, which allows instruments to be wired in parallel and addressed by ID number
- Inductive modem, which we discussed in the previous module

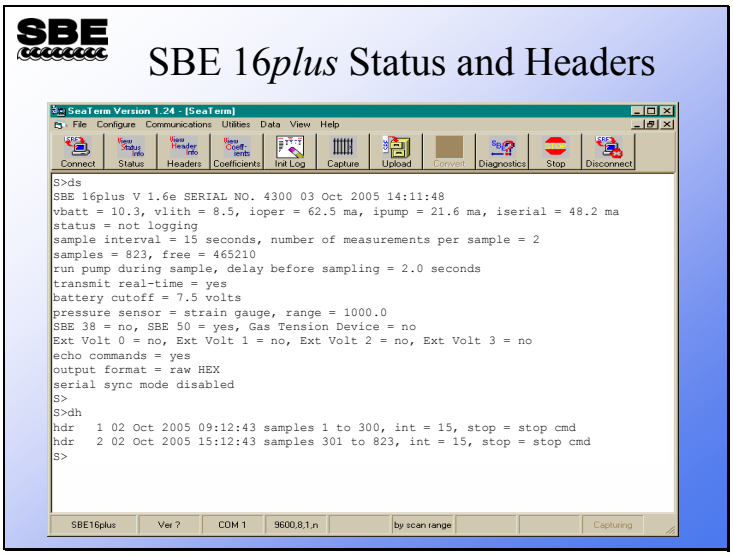
The SBE 37 and 16*plus* are available in models to support each of the three types of serial communication; the SBE 39 is available in both RS-232 and inductive modem models.

Seaterm: Upload Types



Profiling instruments usually transfer data in casts. Moored instruments typically dump all their stored data at once.

SBE 16*plus* Status Report and Data Headers



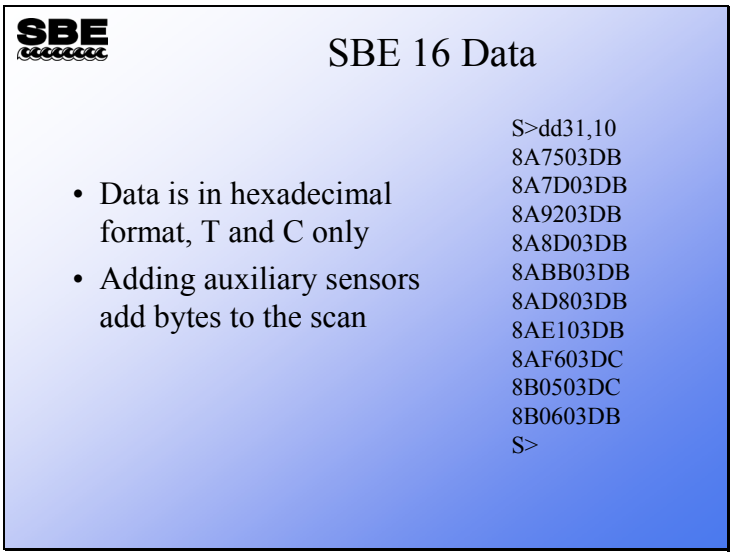
The 16*plus* status report has:

- Firmware revision, serial number, date and time.
- Battery voltage, back-up battery voltage, and operating current.
- Status: logging or not.
- Sample interval and number of measurements that are averaged to make a sample.
- Number of samples stored and amount of space free.
- Parameters related to the pump and auxiliary sensors -
  - pump mode (no pump, run for 0.5 sec before each sample, or run during each sample)
  - delay before sampling (seconds after switching on power that auxiliary sensor measurement is made)
- Transmit real-time data or not.
- Battery cut-off voltage.
- Pressure sensor type and range.
- Whether an external SBE 38, SBE 50, or GTD is attached.
- Which external voltages are sampled.
- Show entered commands on screen as you type?
- Output data format -
  - raw frequencies and voltages in hexadecimal
  - data converted to scientific units but output in hexadecimal
  - raw frequencies and voltages in decimal
  - data converted to scientific units output in decimal; whether salinity and sound velocity output

  Note that uploads initiated via Seaterm's toolbar are always uploaded in raw frequencies expressed in hexadecimal.
- Serial synchronization mode enabled or disabled.

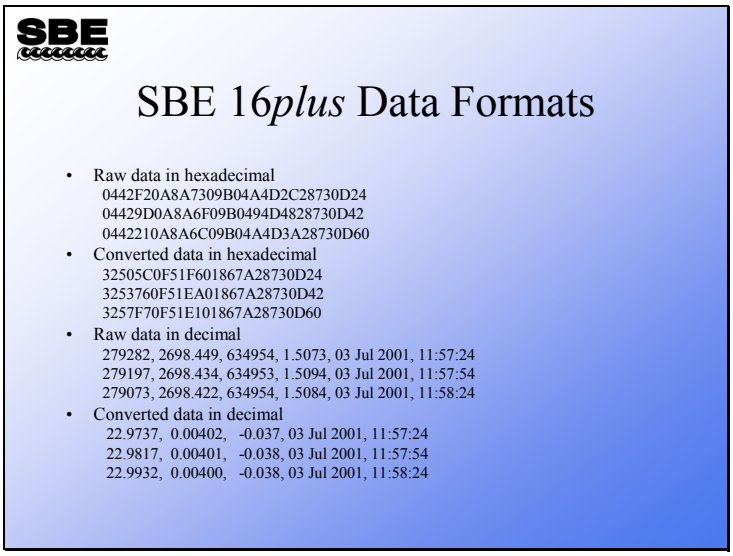
Header entries have start date and time, sample range, and sample interval as well as the reason for ending data collection.

Data Format: SBE 16



This data is an ASCII representation of hexadecimal numbers. This representation allows the data file to be readable with any text editor.

Data Format: SBE 16*plus*



A complete description of these formats is found in the manual.

- **Raw data in hexadecimal example:**

  SBE 16*plus* with strain gauge pressure sensor and two external voltages sampled, example scan = ttttttccccccppppppvvvvvvvvvvvvssssssss
  = 0A53711BC7220C14C17D820305059425980600

- **Converted data in hexadecimal example:**

  SBE 16*plus* with strain gauge pressure sensor and two external voltages sampled, example scan = ttttttccccccppppppvvvvvvvvssssssss
  = 3385C40F42FE0186DE0305059425980600

Note that some of the hexadecimal numbers are scaled. For example, in the raw hexadecimal data, the conductivity frequency is multiplied by 256. In the converted hexadecimal data, temperature is multiplied by 100,000 and conductivity by 1,000,000.

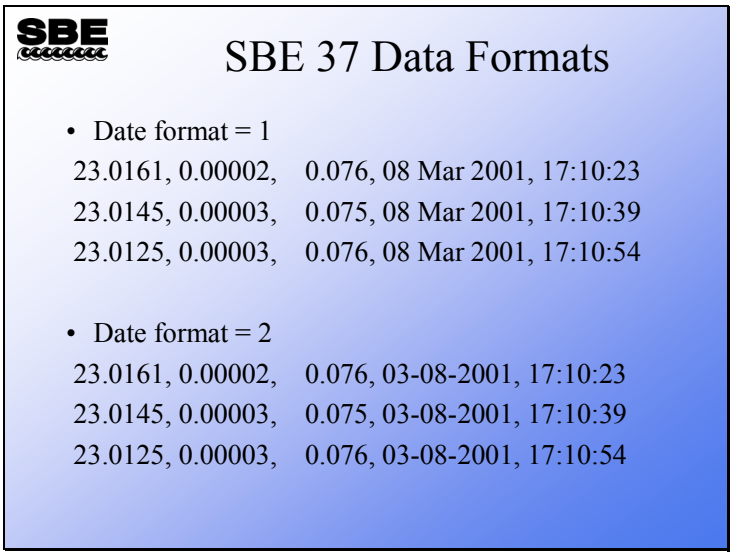
- **Raw data in decimal example:**

  SBE 16*plus* with strain gauge pressure sensor and two external voltages sampled, example scan =
  ttttt, cccc.ccc, pppppp, v.vvvv, v.vvvv, v.vvvv, dd mmm yyyy, hh:mm:ss
  = 676721, 7111.133, 791745, 2.4514, 0.0590, 0.1089, 12 nov 2000, 12:23:05

- **Converted data in decimal:**

  SBE 16*plus* with strain gauge pressure sensor and two external voltages sampled, example scan = ttt.tttt, cc.ccccc, pppp.ppp, v.vvvv, v.vvvv, dd mmm yyyy, hh:mm:ss
  = 23.7658, 0.00019, 0.062, 0.0590, 0.1089, 12 nov 2000, 12:23:05

Data Format: SBE 37



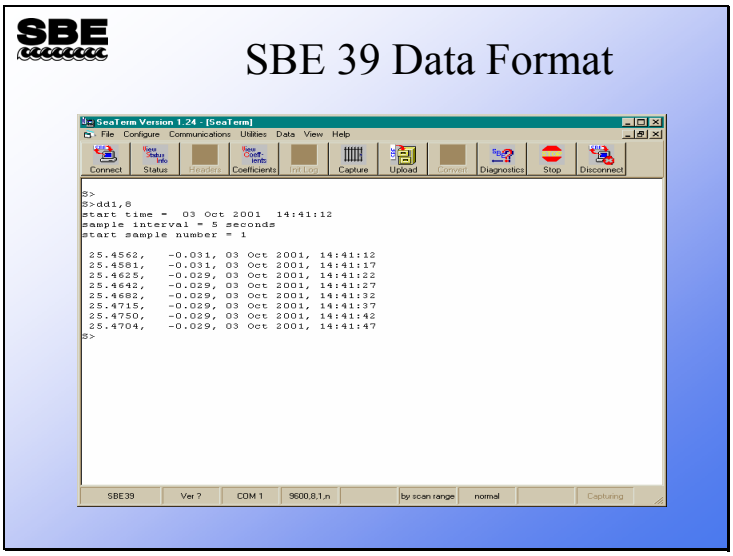
The basic SBE 37 data format is temperature, conductivity, pressure (if installed), date and time. The SBE 37 offers two date formats in the data output:

- dd mmm yyyy
- mm-dd-yyyy.

This is selected with the **format=** command. Note that there are some differences in output format, depending on the specific model of SBE 37 MicroCAT:

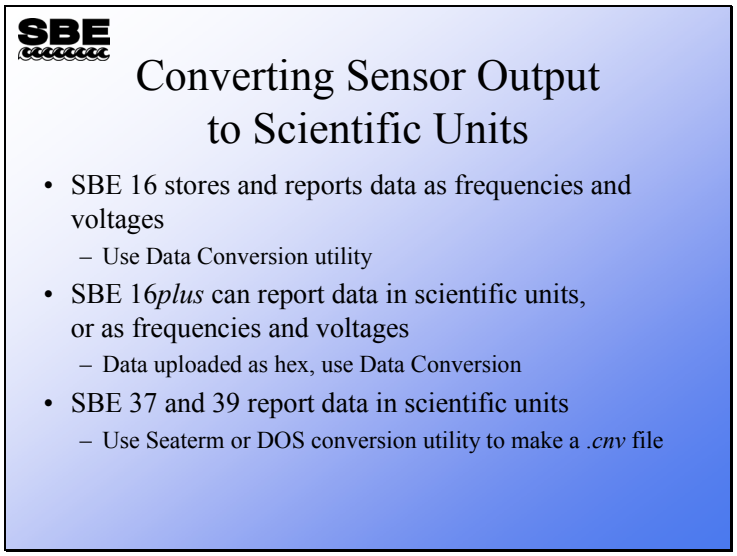
- 37-IM and 37-IMP: The **format=** command also affects the output units for conductivity: S/m for **format=1** and mS/cm for **format=2**.
- 37-SM and 37-SMP: Can also output salinity and/or sound velocity if desired, with the use of the appropriate setup commands. Can suppress storage and output of date and time with the use of the appropriate setup command.
- 37-SI and 37-SIP: Can also output depth, salinity, sound velocity, and/or density sigma if desired, with the use of the appropriate setup commands. Can suppress output of date and time with the use of the appropriate setup command.

Data Format: SBE 39



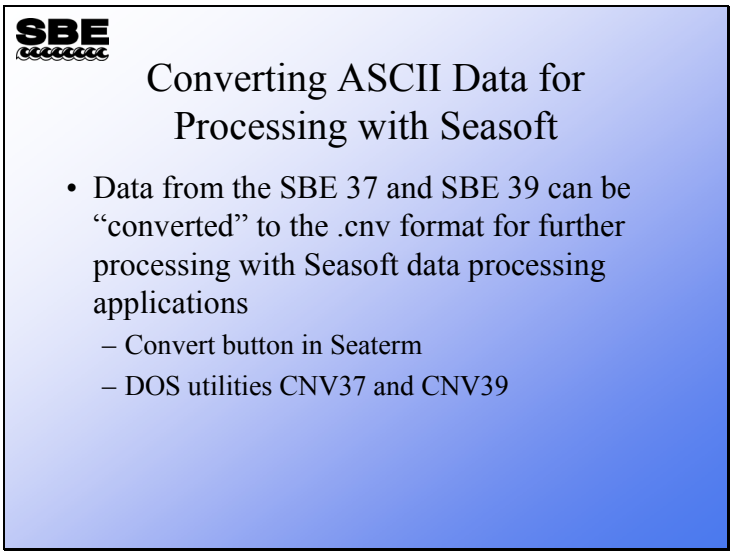
The SBE 39 data format is temperature, pressure (if installed), date and time.

Converting Sensor Output to Scientific Units



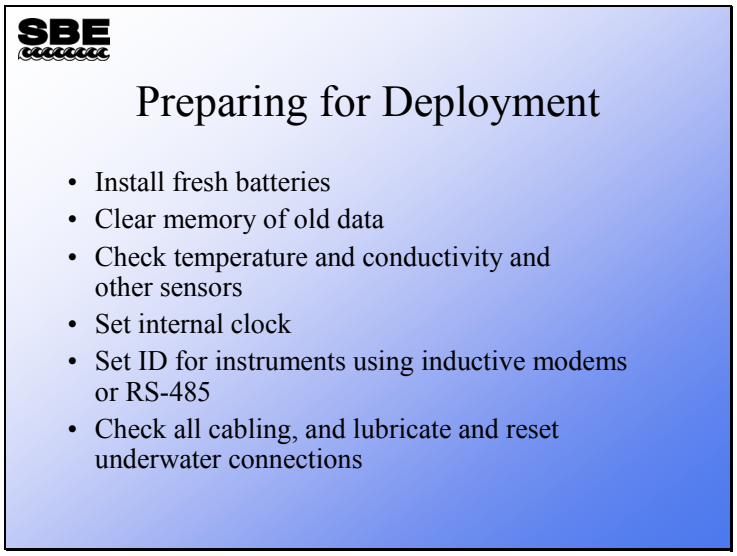
- The SBE 16 requires the same sort of data processing as was discussed in the previous part of the course, beginning with Data Conversion and ending with Bin Averaging.
- The SBE 16*plus* can report data in scientific units. However, when Seaterm's toolbar is used to retrieve data, Seaterm sets the output format to raw hexadecimal data, to provide a file that is compatible with SBE Data Processing. This data requires conversion with the Data Conversion module in SBE Data Processing.
- The SBE 37 and 39 report data in scientific units and Seaterm retrieves the data in this format.

ASCII Data Conversion Utilities



SBE 37s and 39s report data in scientific units in a format that is not compatible with Seasoft's post processing utilities. If you wish to do any processing of this data with SBE Data Processing, you have to convert it to the *.cnv* file format. There is a utility that is part of Seaterm or DOS utilities to perform this conversion.

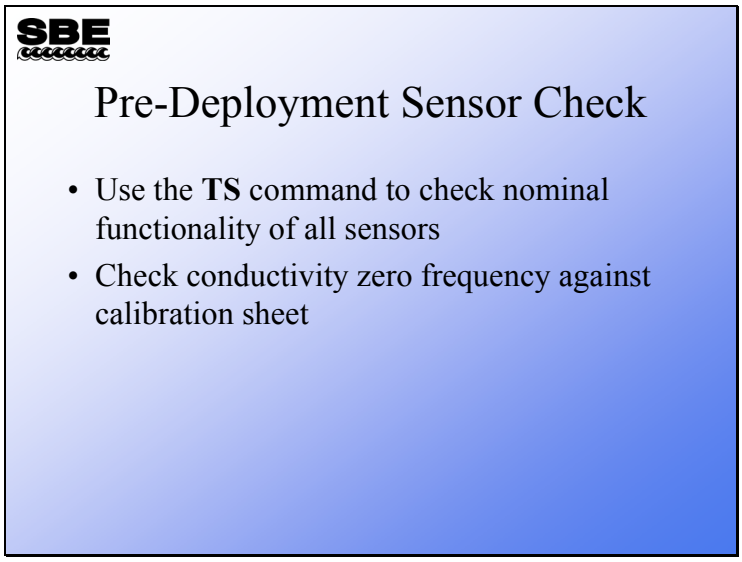
Preparing for Deployment



We are going to discuss preparation for deployment next. Some of these items need little explanation, while others require more consideration.

Sea-Bird instruments stop recording data when the memory is full. It is very important to clear the memory before you start.

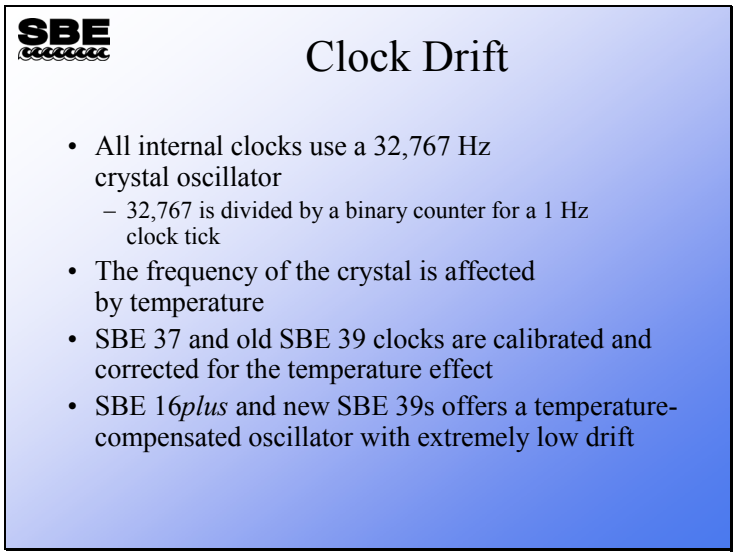
Preparing for Deployment: Sensor Check



Before you invest a great deal of time and effort deploying a mooring, it is a great idea to send your instrument in for calibration. It is an excellent check on its functionality, not to mention its accuracy. If you are unable to do this, check to see that all the sensors are presenting nominally correct output. Sea-Bird moored instruments, with the exception of the SBE 16, have calibration coefficients stored internally and are able to output measurements in scientific units.

The best spot check for the conductivity cell is to observe its zero conductivity frequency. To do this, rinse the cell in distilled or de-ionized water and shake any remaining drops out. The sensor should read very close to the zero conductivity reading on the calibration sheet. If it does not, the cell may be dirty or damaged. Try cleaning it with a non-ionic detergent such as Triton X.

Preparing for Deployment: Clocks

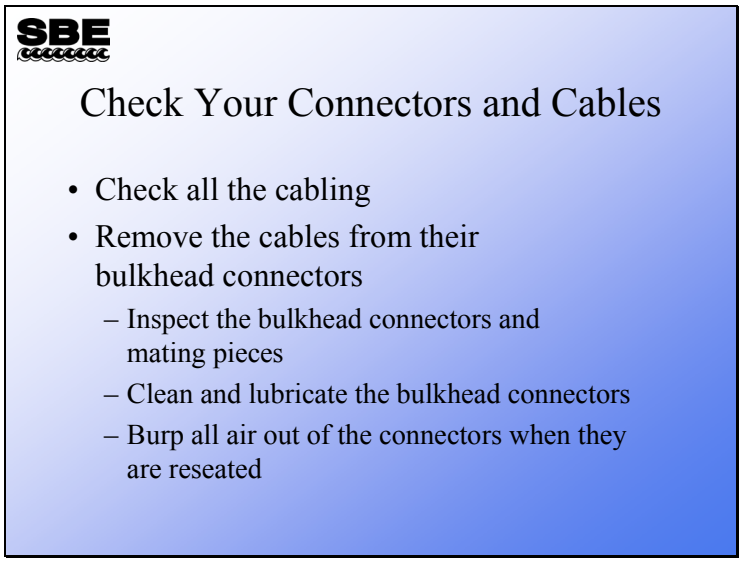


All clocks drift. If you put 10 instruments on a mooring, all set to the same time, and come back 1 year later, they will all report different times. This can lead to some difficulties when you process the data. Clocks drift because of instability of the crystal oscillator that the clocks use to keep time. A small change in oscillator frequency will translate into a clock that runs fast or slow.

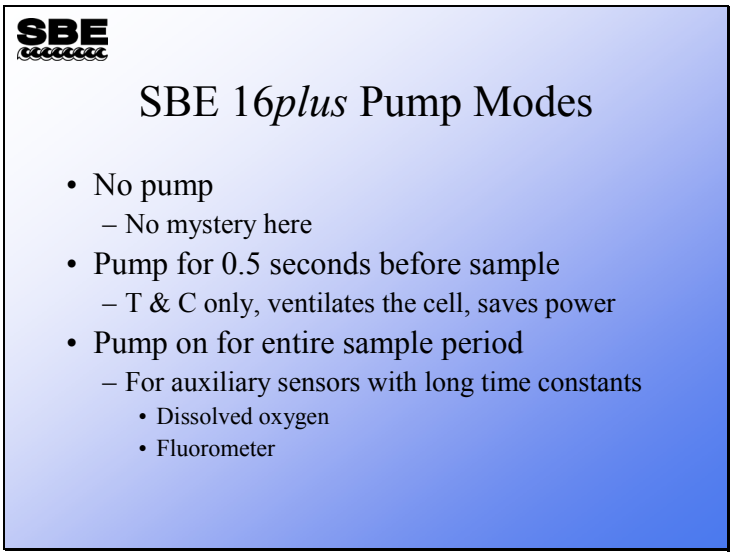
For this reason, Sea-Bird calibrates the clock frequency versus temperature and corrects for drift each time an SBE 37 or older 39 wakes to take a sample. To ensure the time between samples is consistent, each time the instrument wakes and takes a sample, the time to the next sample is set to be the calibrated time interval between samples, not the next clock time. This ensures a data series that is evenly spaced in time. Otherwise, the time between samples would vary depending on temperature's effect on the oscillator.

The SBE 16*plus* and newer SBE 39s use a temperature-compensated oscillator that provides a very stable time base. Previously these were not available in a small enough package to make them practical for a moored instrument.

Preparing for Deployment: Cables



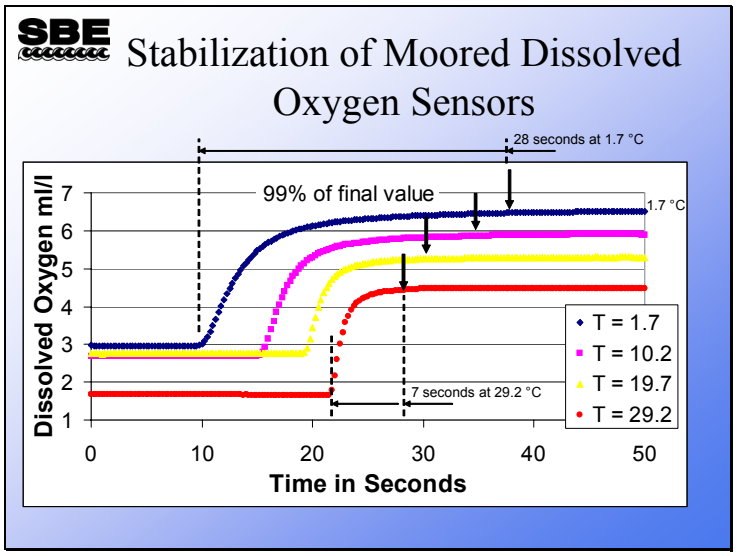
Preparing for Deployment: SBE 16*plus* Pump Operating Modes



Experience with the SBE 41 ALACE CTD has led Sea-Bird to adopt the protocol of ventilating the conductivity cell for a short time before measuring the conductivity, and then turning the pump off. This saves power and has the additional benefit of reducing bio-fouling inside the cell while the pump is off and the instrument is waiting for the next sample. With this protocol the power requirement is small enough to allow long-term deployment at reasonably short sampling intervals (e.g., 15 minutes).

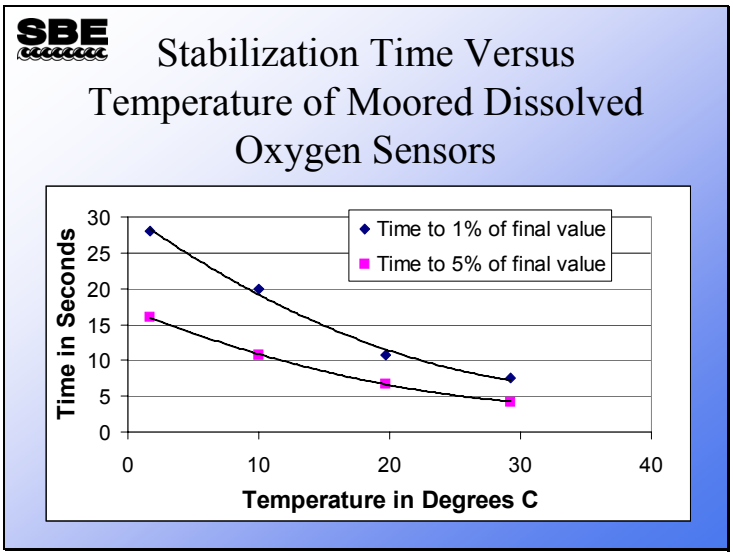
If you are using sensors with a comparatively long time constant, run the pump throughout the sample interval. Recall from the slide that showed the 16*plus* status report, you can set the delay from the start of the sampling period to the moment when the auxiliary sensor is measured. This allows you to give a slow sensor 5 or 6 time constants to equilibrate.

Preparing for Deployment: Setting Up for Dissolved Oxygen Sensors



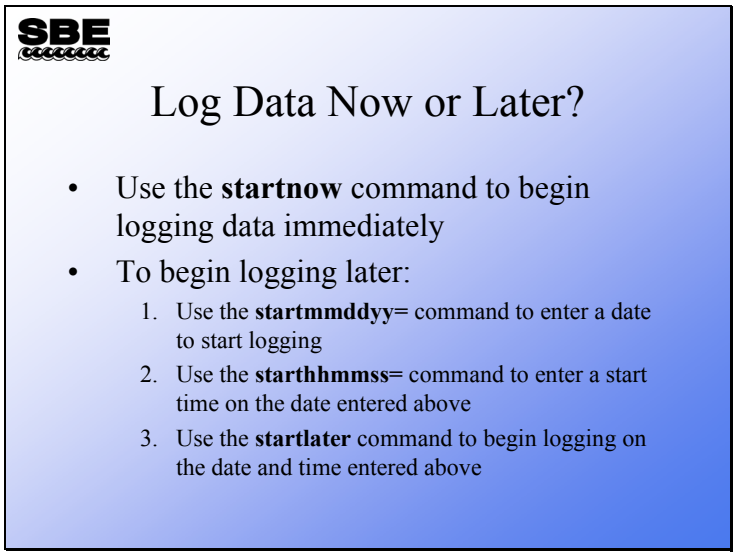
Oxygen sensors installed in moorings are always pumped and are typically plumbed between the pump and conductivity sensor of an SBE 16*plus*. Between samples the pump does not run and water ceases to move past the oxygen electrode. As we have discussed, the electrode of the SBE 43 oxygen sensor is powered by an internal battery. When the water becomes still, the electrode depletes it of oxygen; if the 16*plus* were to continue logging data you would observe oxygen concentration inside the sensor plenum approaching a steady state well below the ambient oxygen levels. When the 16*plus* initiates a normal sampling interval by turning on the pump, you would observe a curve similar to the ones shown above. The water flow establishes a normal boundary layer above the oxygen electrode and the sensor equilibrates to the ambient oxygen level. The time required to reach 99% of the final equilibrium value depends on temperature, warmer water allowing faster equilibration. The arrows on the plot show the point at which the sensor has achieved 99% of the final value at each temperature.

Preparing for Deployment: Setting Up for Dissolved Oxygen Sensors (*continued*)



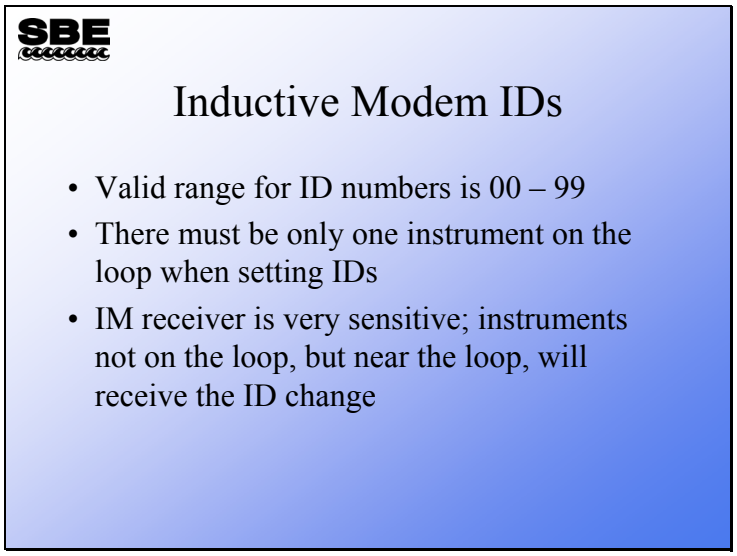
This plot is derived from the preceding plot and may be used to determine the time required from power up and pump turn on to the availability of an acceptable dissolved oxygen sample. For example, if you were working in 20° C water and wanted your oxygen data to be better than 1% of actual ambient oxygen concentrations, you would want the sample interval to be longer than 11 seconds. Set the SBE 16*plus* pump mode to pump during the entire sample time (**mooredpumpmode=2**), and set the delay before sampling to 15 seconds (**delaybeforesampling=15**). We have allowed 4 extra seconds in our sampling time; this ensures that if the instrument finds itself in colder than expected water, that the sample will still be good. Note that longer pump times reduce battery endurance.

Preparing for Deployment: Starting Logging



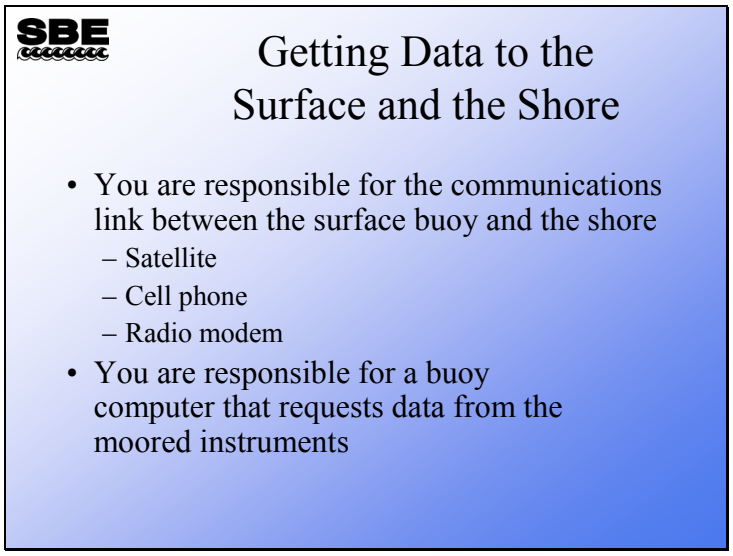
You have the option of setting a logging start time and date, allowing you to begin data collection once the mooring is in place. The risk you run is that you might not place the mooring when you planned to. There are always some risks in life. The alternative is to trim off data that is meaningless at the beginning of the file.

Preparing for Deployment: Inductive Modem Systems



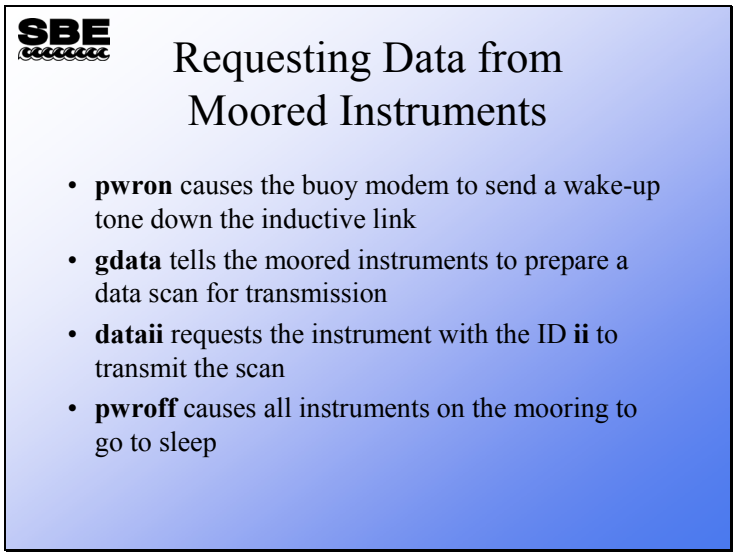
Do not change the ID of an inductive modem equipped instrument when another instrument is on the same loop; this will cause both instruments to take the same ID. The telemetry system will not work properly for those instruments, because they will try to use the link at the same time. The inductive modem receiver in the instruments is very sensitive. Two instruments that are side-by-side will take the same ID even if one of them is not connected to the loop. You must separate IM instruments by at least a meter when you change IDs.

Preparing for Deployment: Inductive Modem Systems (*continued*)



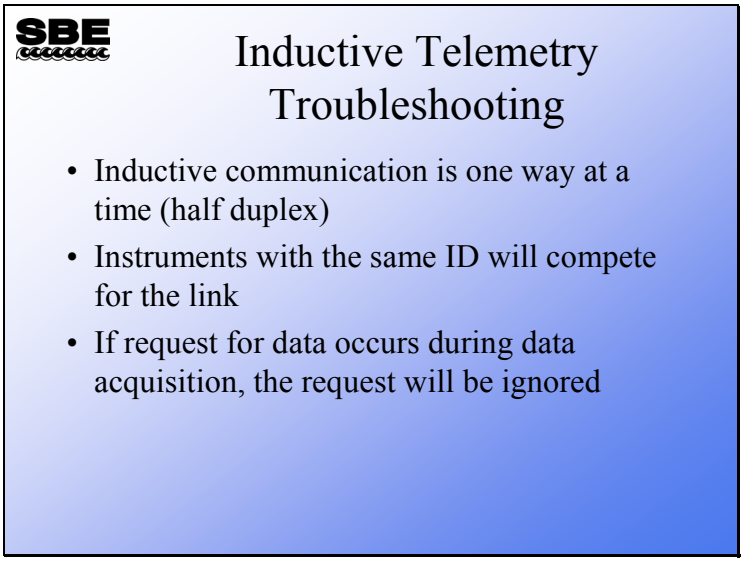
The complete inductive mooring system requires a computer at the surface, to send commands to the instruments via the surface inductive modem and to communicate with the shore. Sea-Bird has customers that use ARGOS satellites, some that use cell phones, and some that use radio modems. It is your responsibility to develop the hardware and software to perform these duties.

Preparing for Deployment: Inductive Modem Systems (*continued*)



Communication with the moored instruments is simple. Sending **pwron** to the surface modem's serial port causes it to wake all the remote instruments with a 4800 Hz tone. Once awakened, the **gdata** command causes the modems on the moored instruments to request the last sample or an average of the samples taken from their instruments (depending on the instrument and its setup). Then each instrument in turn is queried for a sample with the **dataii** command, with **ii** being the instrument ID (for example, **data01** queries the instrument with ID=01). Finally, **pwroff** puts all the instruments to sleep. If no **pwroff** is issued, the instruments go to sleep after 2 minutes. Thus, if the sampling protocol requires more than 2 minutes, a **pwron** must be issued to make sure that none of the moored instruments has gone to sleep.

Preparing for Deployment: Inductive Modem Systems (*continued*)



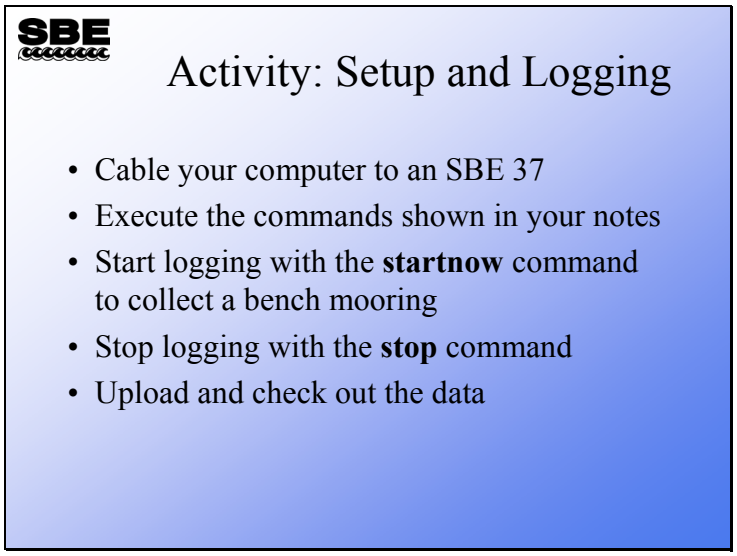
The inductive link is half duplex. This means that only one device on the link may be actively transmitting data at a time. If the situation occurs where two devices are trying to transmit, the communication will be corrupt.

If two devices have the same ID, the above problem will occur whenever that ID is used.

Usually, moored instruments sample on schedule. If the inductive link becomes active while an instrument is sampling, a request for data may be ignored. This can occur because of clock drift in the buoy. If the buoy is equipped with a GPS, the GPS is a good source of time.

A final note on preparing moored instruments for deployment: Application Note 83 provides a checklist for moored instruments, intended as a guideline to assist you in developing a checklist specific to your operation and instrument setup.

Activity

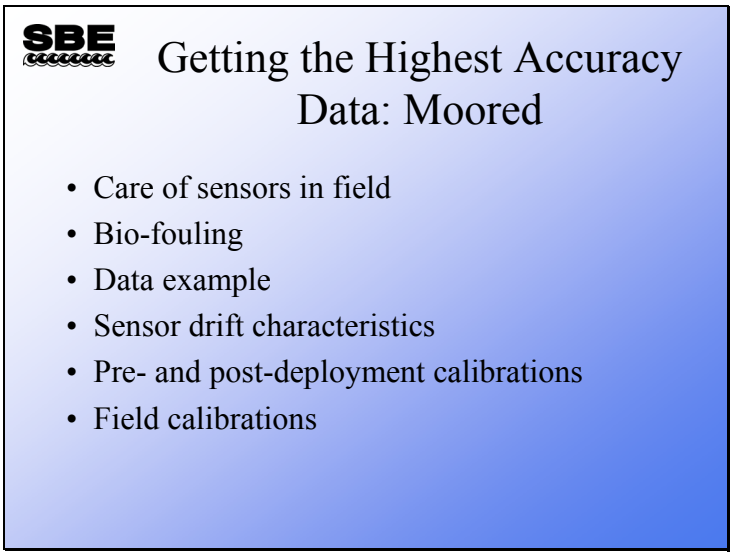


Command	Description
*cn	Take instrument out of calibrate mode
mmddyy=	Set date, month day year
hhmmss=	Set time hour minute second
interval=30	Set sampling interval
samplenum=0	Reset memory
format=1	Set date format to dd mmm yyyy
storetime=y	Store sample time with each sample
txrealtime=y	Transmit sample as it is taken
syncmode =n	Disable serial sync mode
ds	Get instrument status to verify setup

Module 12

Getting the Highest Accuracy Data from Moored Instruments

Overview

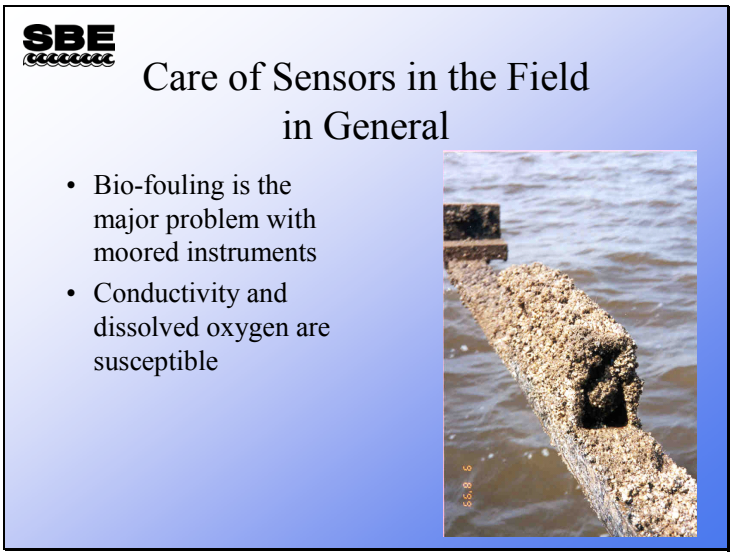


In the module we will discuss the means to get the highest accuracy in your moored measurements. This includes care of sensors in the field and understanding sensor drift characteristics. Moored instruments can exhibit unexpected drift in conductivity. Topics covered include pre- and post-deployment calibrations, field calibrations, and bio-fouling.

By the end of this module you should be able to:

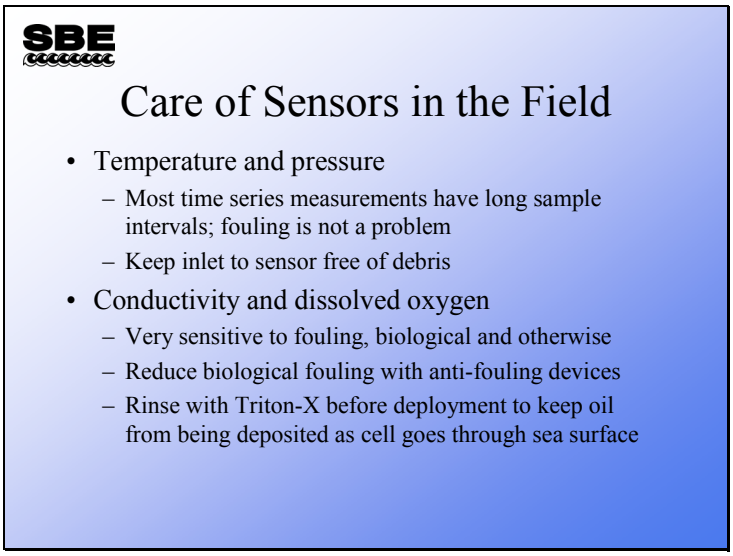
- Care for your moored sensors
- Know how to reduce bio-fouling
- Understand sensor drift
- Correct data for sensor drift with pre- and post-calibration
- Compare data from your mooring with data collected with a profiling instrument

Care of Sensors in the Field



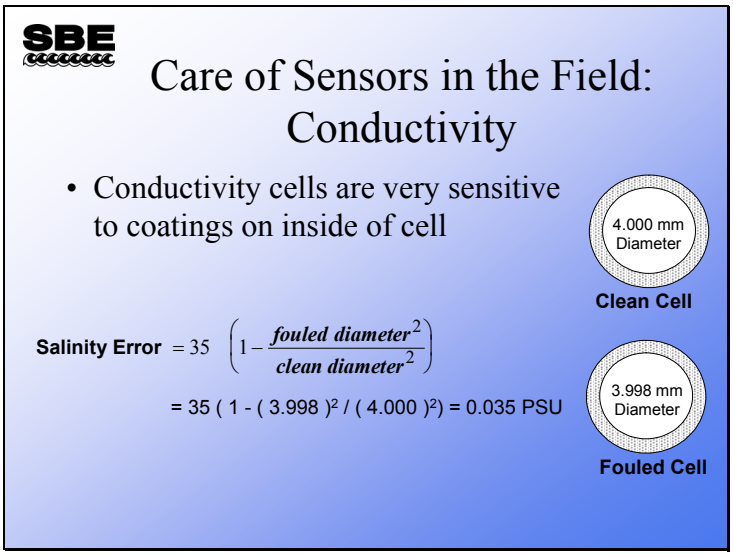
This SBE 37 is deployed in the tide waters of Georgia. Biological activity surges when the water temperature exceeds 20 °C. The researcher uses extra bio-fouling protection on each end of the conductivity cell and protects the pressure housing of the instrument with packing tape and silicon grease.

Care of Sensors in the Field



As we have discussed, thermometers are very robust. In moored applications, the sampling interval is much longer than the time constant of the thermometer, so except in extreme conditions fouling does not affect thermometers.

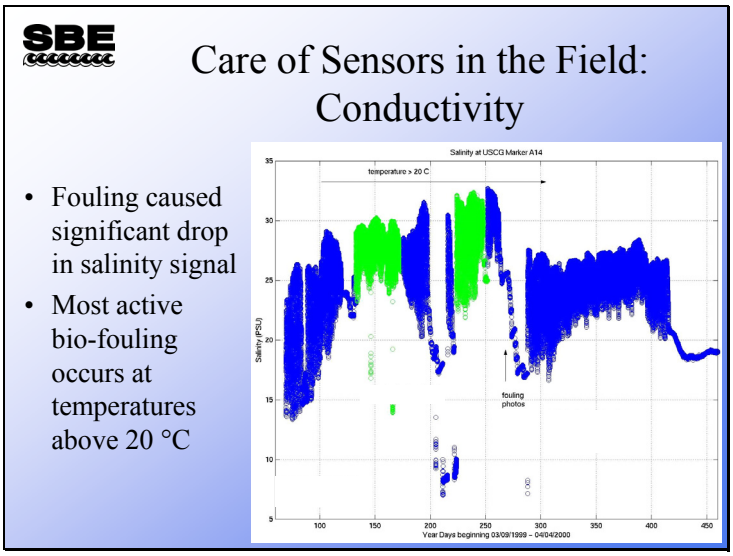
Care of Sensors in the Field: Conductivity



Conductivity sensors are another matter. Recall this slide from a previous discussion. A very thin coating can change the cell geometry, having a large effect on the conductivity measurement.

Care of Sensors in the Field: Conductivity (*continued*)

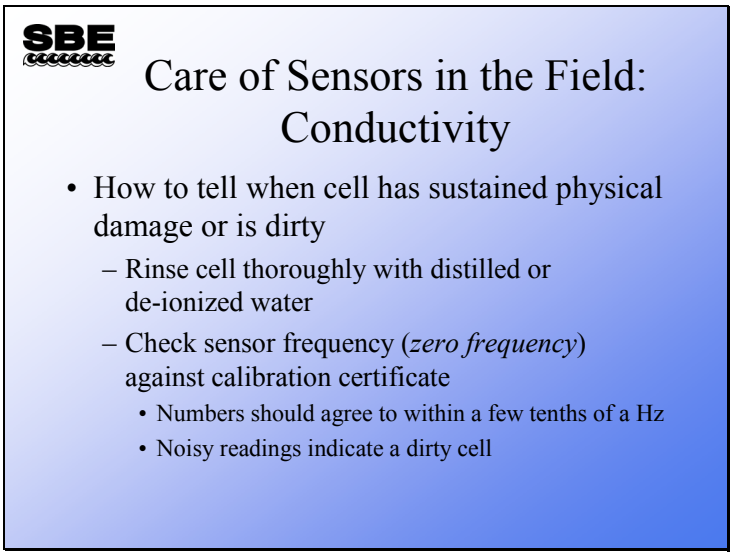
Care of Sensors in the Field: Conductivity (*continued*)



This plot is data collected at the site pictured on this module's second slide. Looking at the data set, it is obvious where fouling overwhelmed the instrument. At this site, it was not uncommon for larger animals to take up residence in the conductivity cell, resulting in a large disturbance in the data. Bio-fouling protection is meant to kill bacteria and larval animals that would settle inside the cell. Large animals (like a crab) will be killed, but more slowly, falling out of the cell after death.

We are grateful to Susan Elston at Skidaway Institute of Oceanography, Savannah, Georgia for sharing her photographs and data with us.

Care of Sensors in the Field: Conductivity (*continued*)

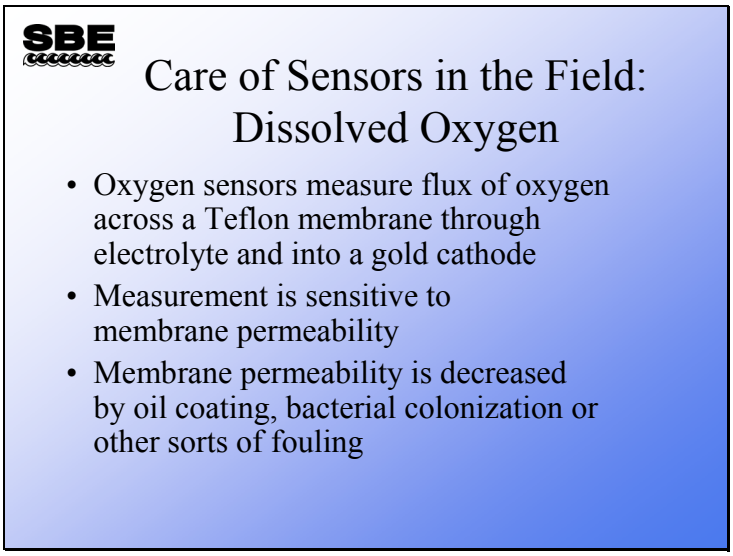


As we discussed in the previous module, checking the zero frequency of a conductivity cell is a great way to do a spot check on the health of the sensor.

If you are servicing moorings and do not intend to bring them in for calibration, a cleaning of the conductivity cell with hot 10% Triton-X solution is a good idea. If you suspect that the cell has been overrun by calcareous organisms, then a rinse with 10% HCl will help by removing any calcium carbonate that may have been deposited.

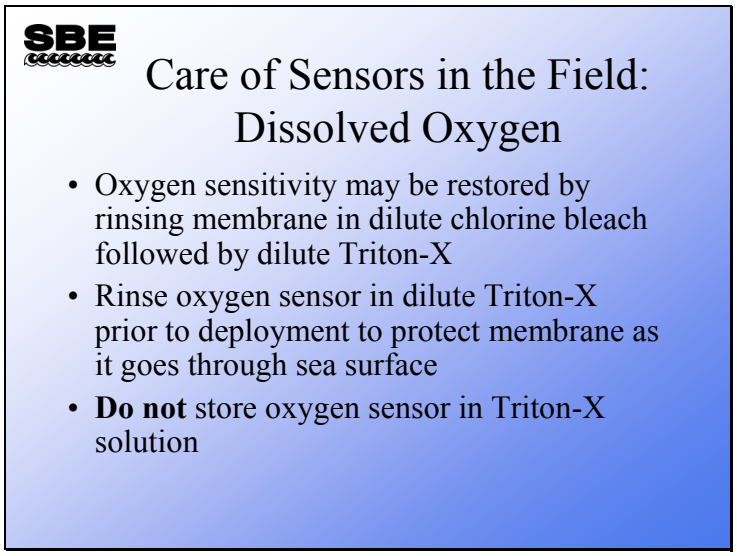
The conductivity cell is made of a glass tube, with cylindrical platinum foil electrodes within. **A brush through the cell risks dislodging the electrode and ruining the cell.** Further, the electrodes are coated with a finely divided metallic platinum known as platinum black. This coating is delicate and will be damaged by a brush.

Care of Sensors in the Field: Dissolved Oxygen



Oxygen sensors become less sensitive when then are fouled. One way to spot check your sensor is to place it in clean, quietly stirred water. You should get a reading near the oxygen saturation value for that temperature. Oxygen saturation is difficult to achieve; vigorous stirring will almost always over-saturate, and water that is changing temperature can be over- or under-saturated. Remember that the oxygen electrode depletes oxygen at its surface; it requires moving water to make an accurate reading.

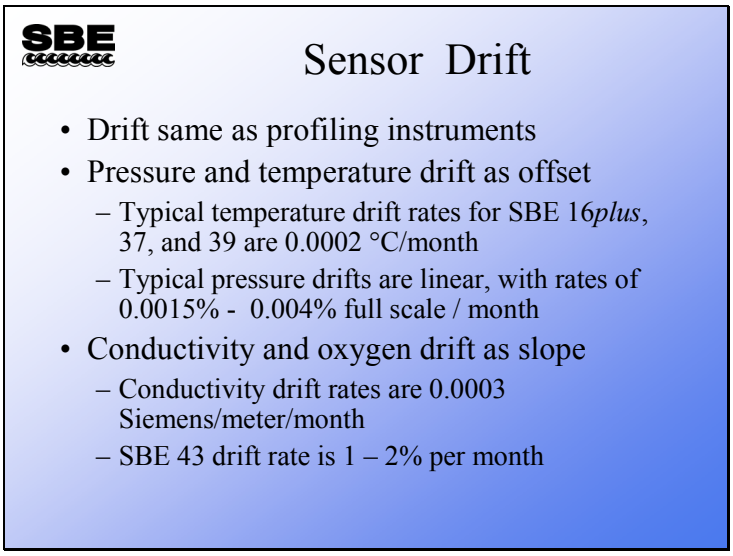
Care of Sensors in the Field: Dissolved Oxygen (*continued*)



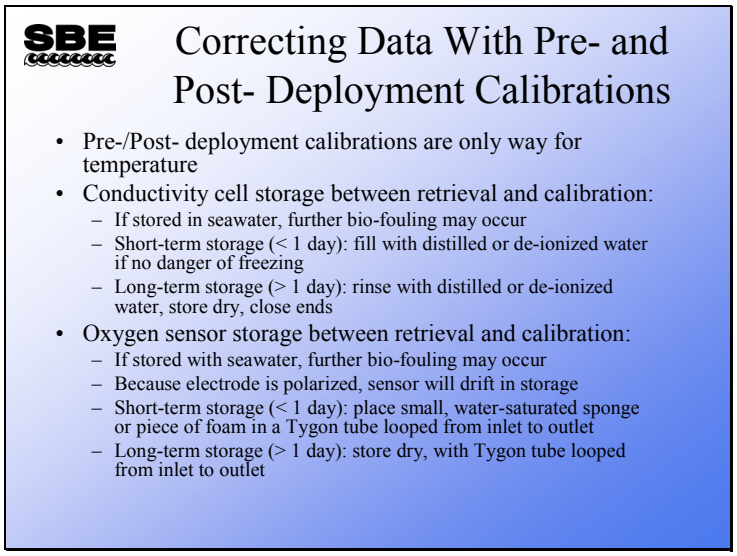
Clean your dissolved oxygen sensor with a 50:1 chlorine bleach solution (50 parts de-ionized water to 1 part chlorine bleach). Follow this with a wash with a 1% Triton-X solution. Repeat these 2 steps as necessary.

See Application Note 64 for details on oxygen sensor cleaning and storage.

Correcting Data



Correcting Data



Conductivity cell:

- Short-term storage: If there is no danger of freezing, store the conductivity cell with distilled or de-ionized water in Tygon tubing looped around the cell. If there is danger of freezing, store the conductivity cell dry, with Tygon tubing looped around the cell.
- Long-term storage: Since conditions of transport and long-term storage are not always under the control of the user, we recommend storing the conductivity cell dry, with Tygon tubing looped around the cell ends. Dry storage eliminates the possibility of damage due to unforeseen freezing, as well as the possibility of bio-organism growth inside the cell.

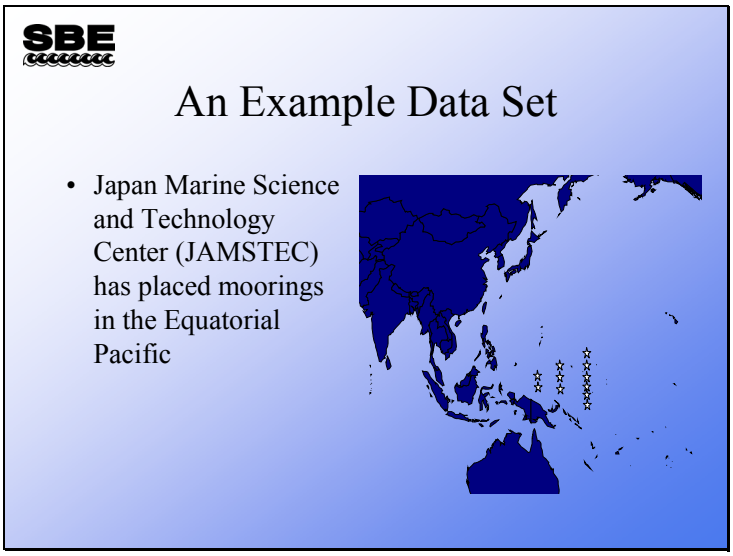
See Application Note 2D for details.

Oxygen sensor:

- Short-term storage: If there is no danger of freezing, place a small piece of clean sponge, *slightly dampened* with fresh, clean water, in the center of the tubing (not near the membrane). If there is danger of freezing, store the oxygen sensor dry, with Tygon tubing looped from inlet to outlet.
- Long-term storage: Since conditions of transport and long-term storage are not always under the control of the user, we recommend storing the oxygen sensor dry, with Tygon tubing looped from inlet to outlet. Dry storage eliminates the possibility of damage due to unforeseen freezing, as well as the possibility of bio-organism growth inside the cell.

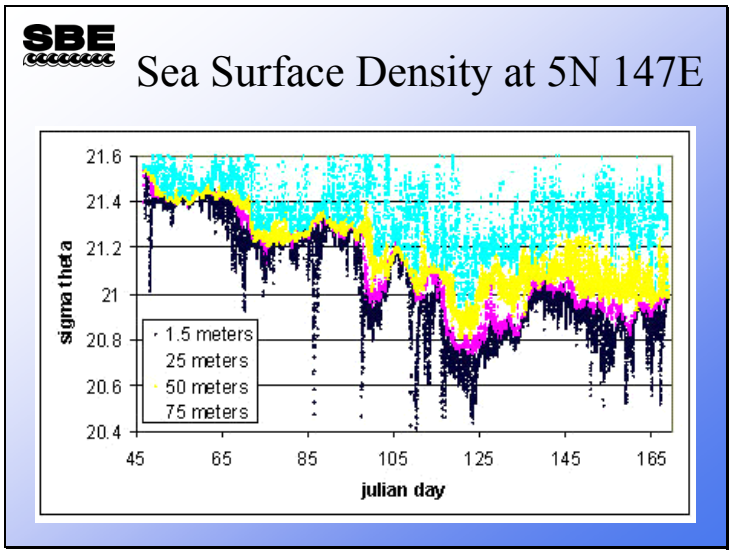
See Application Note 64 for details.

Correcting Data Example

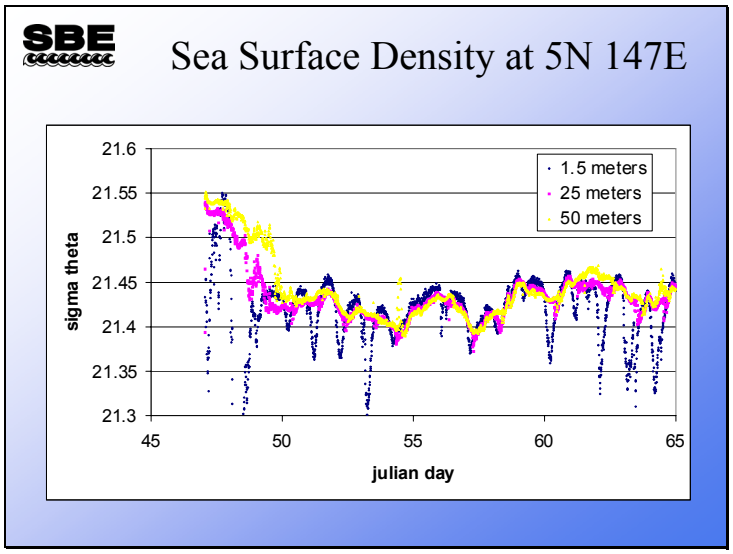


We are going to look at the results of a mooring program carried out by the Japan Marine Science and Technology Center, JAMSTEC. This agency has a mission similar to NOAA in the US. JAMSTEC has placed moorings in the Eastern Equatorial Pacific, which use inductive telemetry to report data in real time via the ARGOS satellite system. The mooring program started in 1998 and continues today.

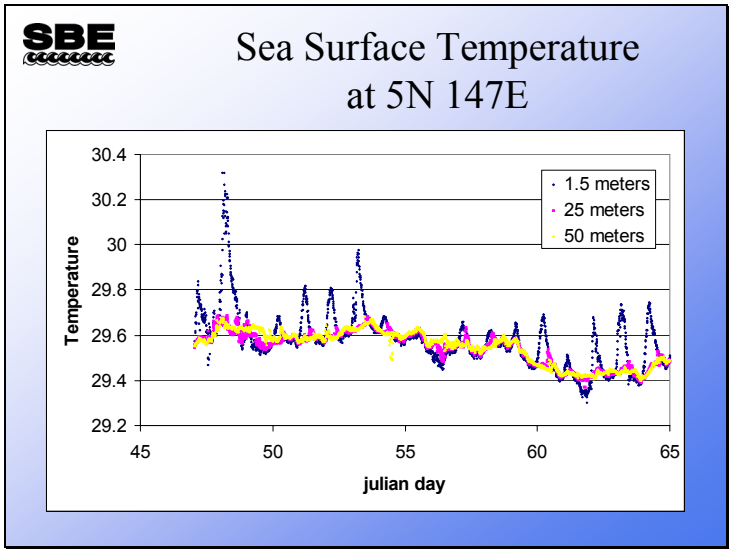
Correcting Data: Example (*continued*)



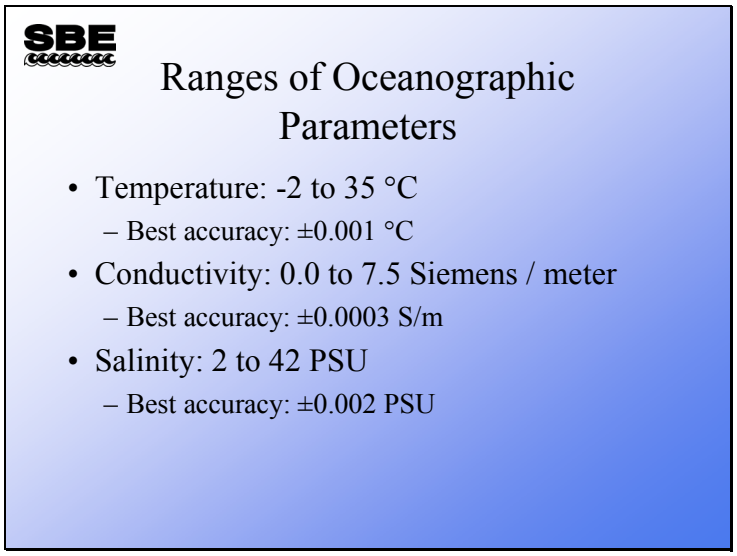
Correcting Data: Example (*continued*)



Correcting Data: Example (*continued*)

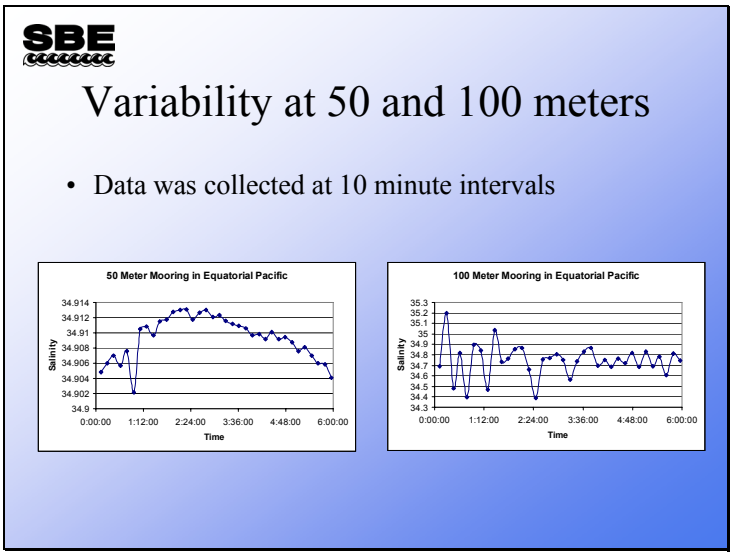


Correcting Data: Review



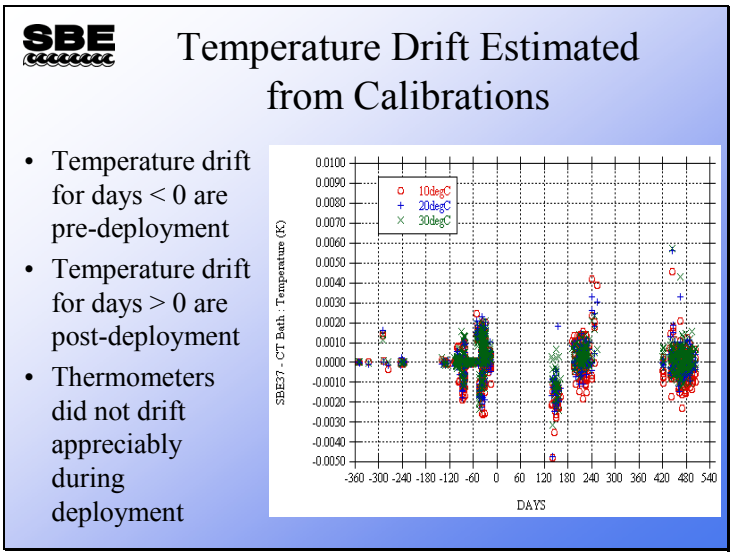
We saw this slide in module 0 in the introduction to oceanographic concepts. These ranges and accuracies will provide a bench mark to evaluate the data that follows.

Correcting Data: Review



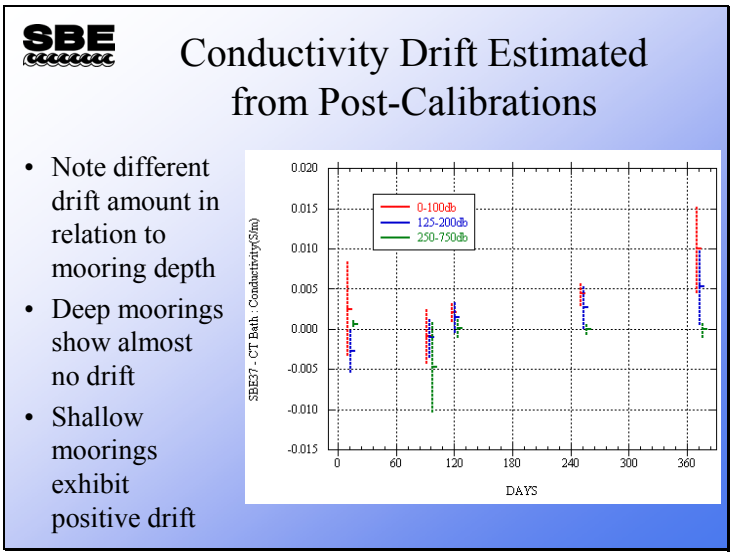
We are going to be comparing data collected by moored instruments with data collected in a CTD profile. It is important to keep in mind that even though the mooring is fixed in place, the ocean moves around it. There can be substantial variability over a fairly small time interval. Most of the time there is little hope of having the CTD in place at the moment the moored instrument is taking a measurement.

Correcting Data: Example (*continued*)



JAMSTEC has installed calibration equipment that allows them to monitor the drift of their sensors before they are deployed. The plot above shows drift of their temperature sensors before and after deployment at three temperatures. As you can see from the plot, with a few exceptions the thermometers are very stable: ±0.002 ºC is within the initial accuracy specified for the SBE 37.

Correcting Data: Example (*continued*)

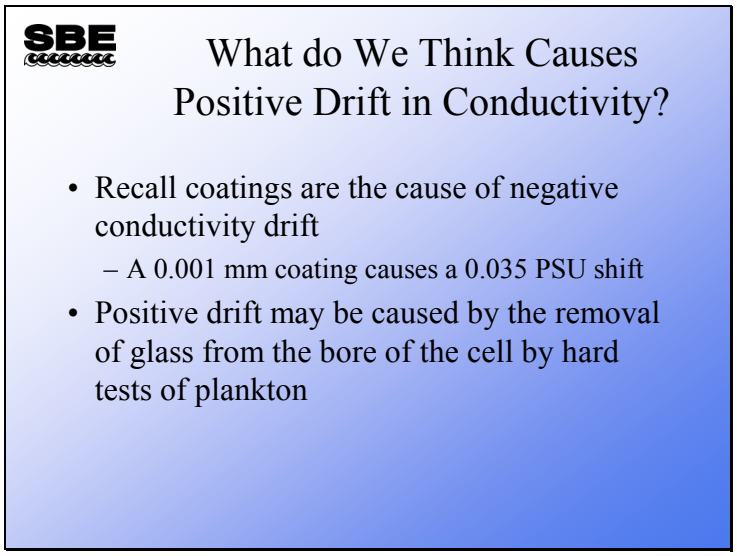


In this plot the drift is estimated at a conductivity value of 6 S/m, and instruments are lumped by mooring depth. Instruments moored in deep water show almost no drift. Those within the surface layer show a positive drift that increases with time. Drift in conductivity sensors is caused by a change in the cell characteristics - either a change in the cell dimensions or electrode characteristics. Note the large error bars on the plot; conductivity drift often has an episodic nature owing to cell fouling due to handling or deployment. The mooring recovered at 90 days has larger error bars and the only negative drift shown. This reinforces the idea that there may have been some incident at or before deployment responsible for the observed drift.

Conductivity: Positive Drift

We have no substantiated ideas regarding positive drift, although it has been observed by researchers in various parts of the world. Anecdotally, when positive drift is observed, it occurs in the instruments in the surface part of the mooring. Also, it seems to occur in areas of high productivity and in areas with strong surface currents.

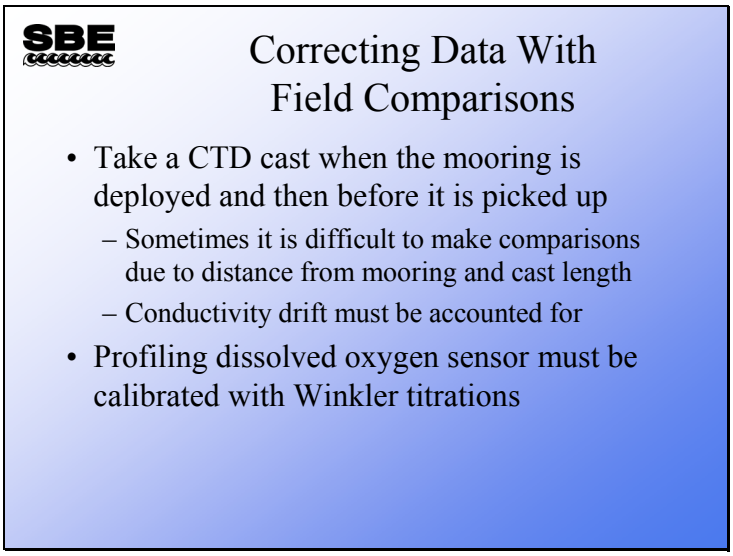
Conductivity: Positive Drift (*continued*)



One possibility is that the hard parts of phytoplankton may abrade the glass of the cell as they pass through. This causes the cross-sectional area of the cell to increase. The conductivity measurement depends on the cell volume; an increase in cross-sectional area will cause the volume to increase. If a cell is calibrated with a starting volume V and the volume is increased at a later time to $(V+\Delta V)$, the conductivity value calculated with the original coefficients will produce a calculated conductivity that is high of correct.

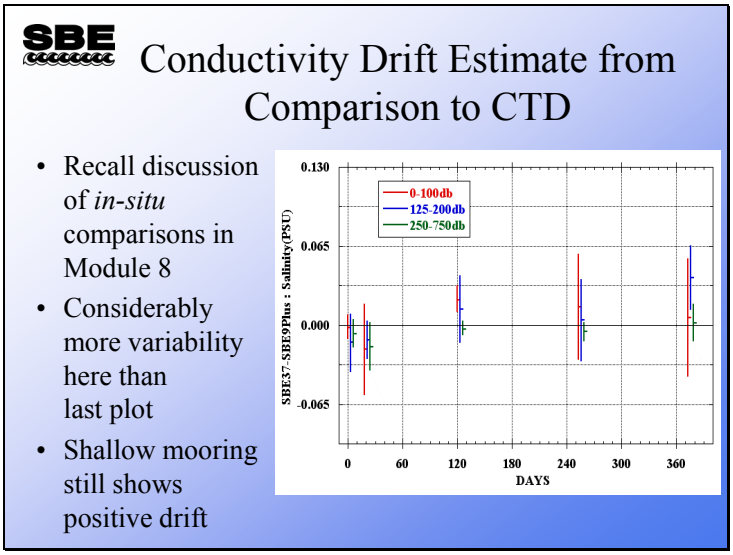
You might think that we could measure the volume of the cell and observe the change in volume. The diameter increase that would produce the errors we are seeing are in the micron range. This change in volume could not be measured gravimetrically. Further, the cross-section of the original cell is not uniform throughout its length, and the abrasion is probably not uniform either, so a comparison of cross-section is not viable.

Correcting Data



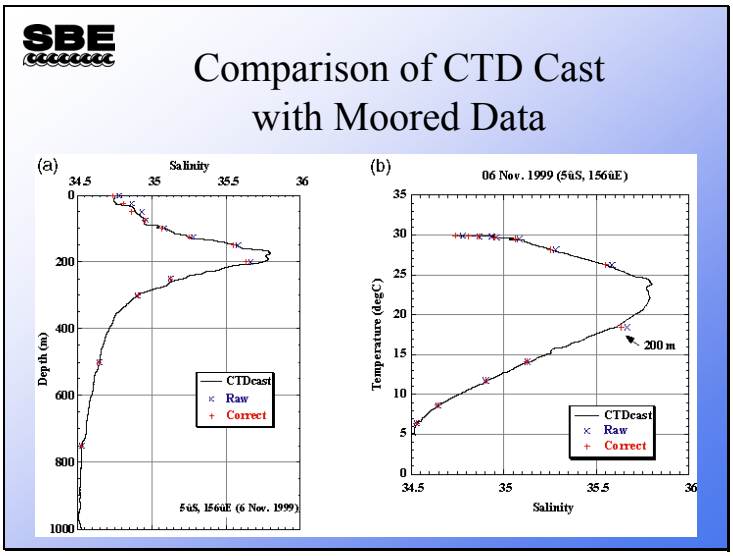
Sea-Bird does not supply software to correct time series data. These corrections are similar to those done on a cast basis for profiled data. An incremental offset is applied to temperature data, assuming the offset drift is linear and monotonic throughout the deployment. For conductivity, an incremental slope is applied to the time series, again assuming that the slope change is linear and monotonic throughout the deployment period.

Correcting Data: Example



Here is a salinity comparison of CTD profiles with mooring data; the data is presented as moored SBE 37 minus SBE 9*plus* CTD. The scale of this plot is much larger than in the plot we looked at on page 20, because the difference in salinity values is much higher. Note that the deep comparisons show little difference, but the variability is quite high in the surface layer. Recall our earlier discussion of calibration by *in-situ* sampling and the plots from the Hawaii Ocean Time Series data.

Correcting Data: Example (*continued*)



Here is a plot of a CTD cast with the mooring data overplotted on it. Raw and corrected values are shown. Although the scale is rather coarse, the correction improved the agreement between the instruments.

Correcting Data: Example (*continued*)

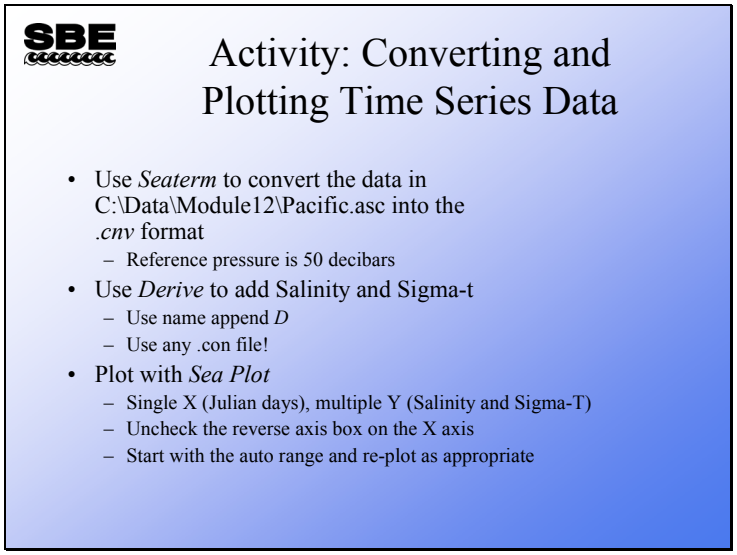
In-situ Comparison Statistics:
Mooring – CTD (all in PSU)

	Raw	Corrected by Calibration
Mean	0.0152	-0.0148
Median	0.0168	-0.0069
Standard Deviation	0.0397	0.0422

Here are the statistics from the analysis of seventy SBE 37s deployed for various intervals from 13 days to over a year. It is instructive to note that the mean and median for the raw data are very similar. The data correction process shifted the mean to a negative value, but did not improve its magnitude. The median however was improved, so the data analysis was successful for most instruments. The large mean and standard deviation are likely due as much to surface variability as to measurement errors.

Plots and statistics taken from:
Matsumoto et. al.,(2001) The time drift of temperature and conductivity sensors of TRITON buoy and the correction of conductivity data. JAMSTECR, 44

Activity



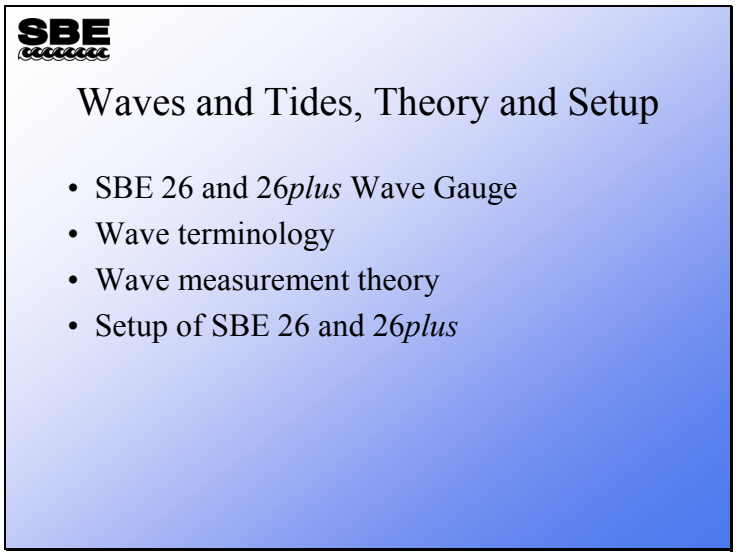
A note about .con files and data from SBE 37 MicroCATs:

The SBE 37 is not user-configurable (i.e., it cannot interface with auxiliary sensors), and it outputs converted data in engineering units (using calibration coefficients programmed into the instrument). Therefore, it does not have a .con file (remember that the .con file defines what sensor data is in the data stream and also defines the calibration coefficients). But, SBE Data Processing was originally written to process data from instruments that do have a .con file, and the Derive module therefore requires the selection of a .con file before it will allow you to select the variables to be derived. You can select any .con file; the selection will have no impact on the results.

Module 13

Wave and Tide Instruments: Theory and Setup

Overview

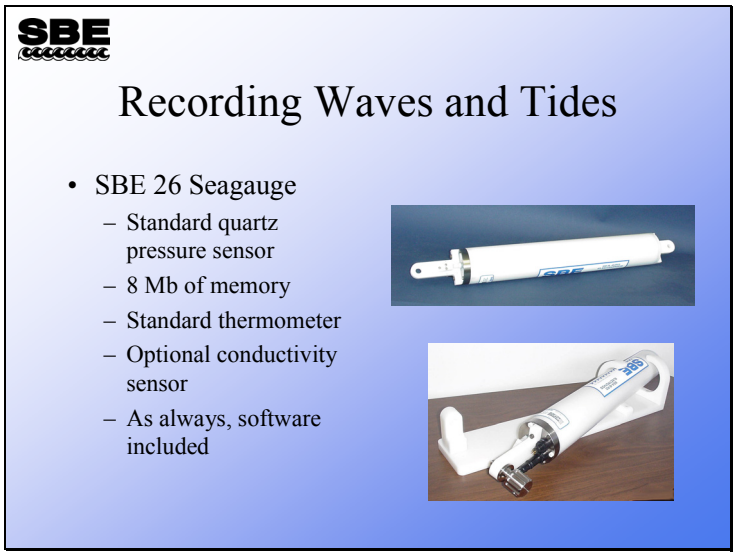


In this module we will be discussing Sea-Bird's SBE 26 and 26*plus* wave and tide recorder. We will spend some time on wave terminology and measurement theory. This topic tends to get very mathematical quickly, so we will just hit the high points. Finally, we will discuss setting up an SBE 26 and a 26*plus* for deployment.

By the end of this module you should be:

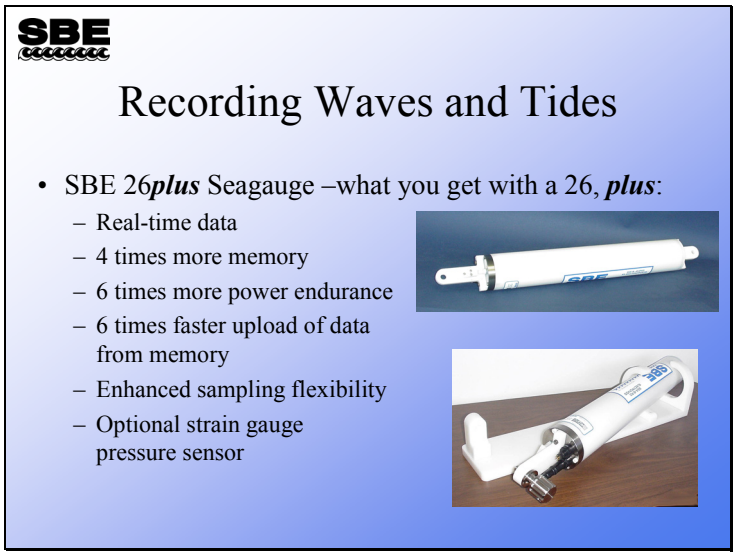
- Able to describe what sort of waves we are measuring.
- Aware of the limitations of the measurement technique.
- Able to set up an SBE 26 and 26*plus* for deployment.

SBE 26 Wave and Tide Recorder



The SBE 26 has been in the field since 1989, and over 400 of these instruments were manufactured. The SBE 26 uses the same pressure sensor as the 9*plus*, but the pressure range is much smaller to provide higher resolution. A temperature sensor is standard equipment, and an SBE 4 conductivity sensor may be added as an option.

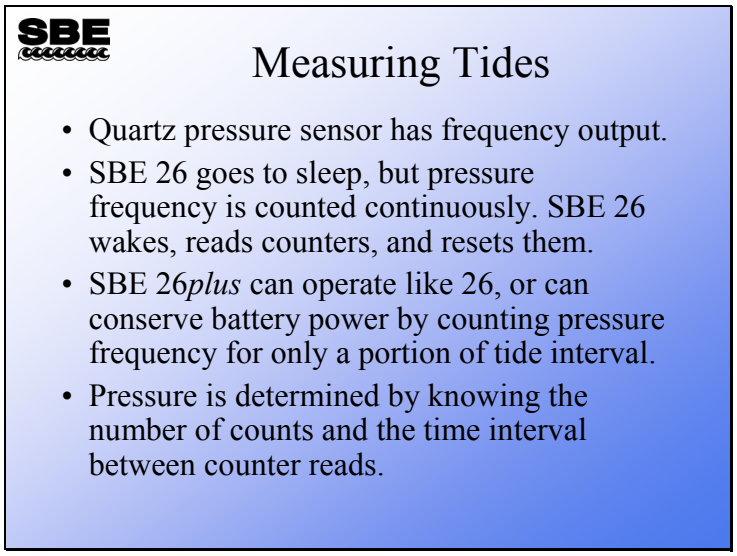
SBE 26*plus* Wave and Tide Recorder



The SBE 26*plus*, an enhancement of the SBE 26, was first manufactured in 2003. While the outside looks the same, and maintains the same dimensions (allowing you to reuse mounting hardware purchased / fabricated for the SBE 26), there are many improvements on the inside. Major improvements / new features are described below:

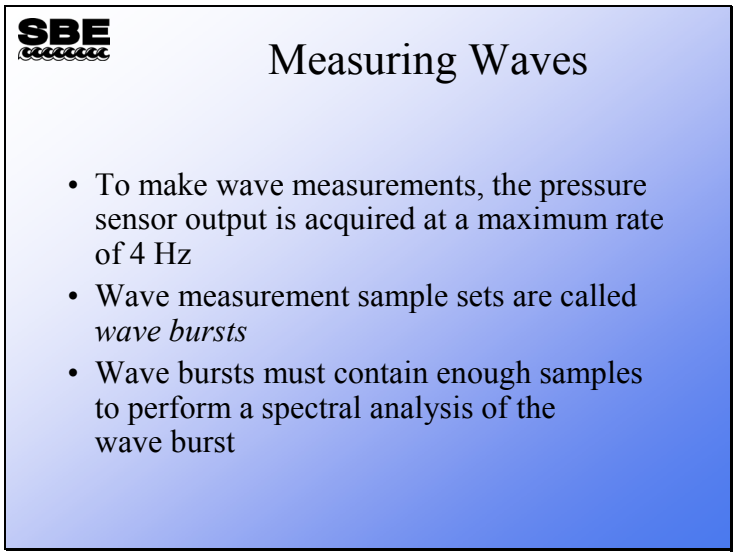
- Real-time data –output tide data, wave data, and/or wave statistics in real-time, in addition to recording in memory
- Four times more memory, and it is FLASH RAM instead of CMOS static RAM
- Six times more power endurance – more batteries fit in the housing, and the electronics draw less power
- Six times faster upload of data from memory, with the use of binary upload at high baud rate
- Enhanced sampling flexibility, allowing tide sampling to be programmed to measure tides for only a portion of the tide interval, conserving power even more
- Optional strain gauge pressure sensor for wave sampling applications, providing reduced accuracy at reduced cost
- Improved temperature accuracy (0.01 °C vs 0.02 °C) and resolution (0.001 °C vs 0.01 °C)
- Improved clock / counter accuracy
  Quartz TCXO 1 ppm per year aging vs 2 ppm per year aging
  Real-time clock 2ppm accuracy vs 5 ppm accuracy

Measuring Tides



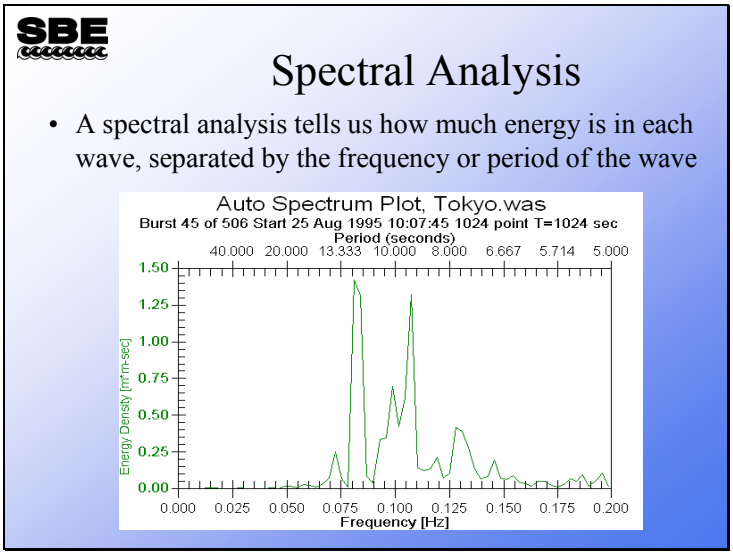
By accumulating pressure sensor frequency counts for the whole sample interval, the SBE 26 / 26*plus* integrates the pressure signal over the entire sampling time. If the sample time is sufficiently long, the influence of surface waves is removed.

Measuring Waves



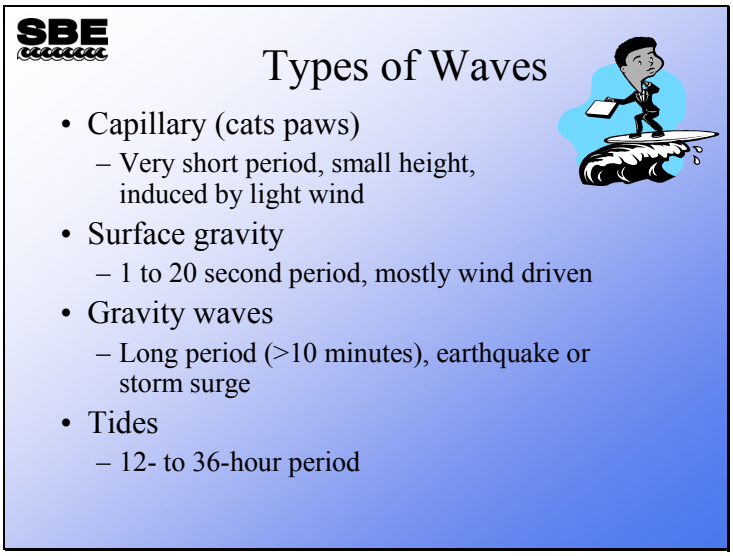
The spectral analysis of wave burst is based on the Fast Fourier Transform. Because of this, the analysis is most accurate if the number of wave burst samples is a power of 2. Further, the more samples in the wave burst, the more accurate the estimation of the wave spectrum. You must balance the desire for accuracy with the endurance of memory and batteries.

Wave Frequency Spectrum



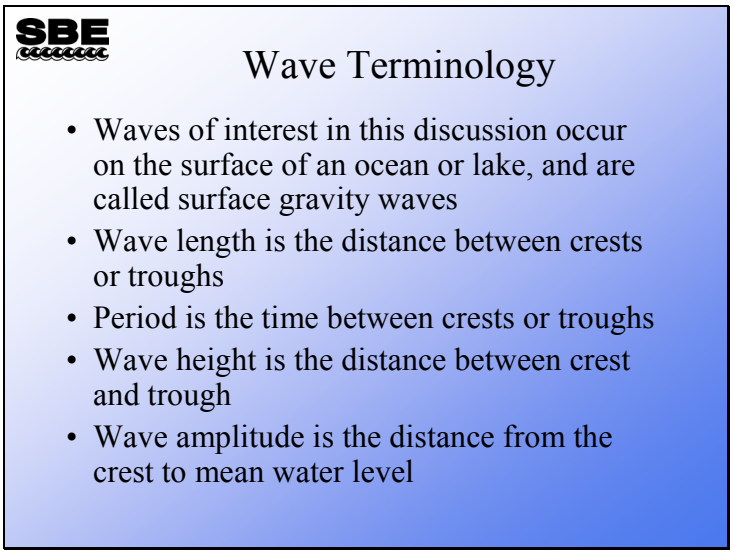
The characteristics of the spectral analysis are determined by the number of data points in the wave burst, the sample rate, and the physical location of the SBE 26 or 26*plus*. The characteristics we are speaking of are the band width or frequency resolution and the maximum frequency of our analysis.

Measuring Waves: Background



The SBE 26 and 26*plus* are engineered to measure surface gravity waves and tides. Tides are actually waves with very long periods. These two phenomena are those of most interest to scientists and engineers.

Measuring Waves: Background (*continued*)

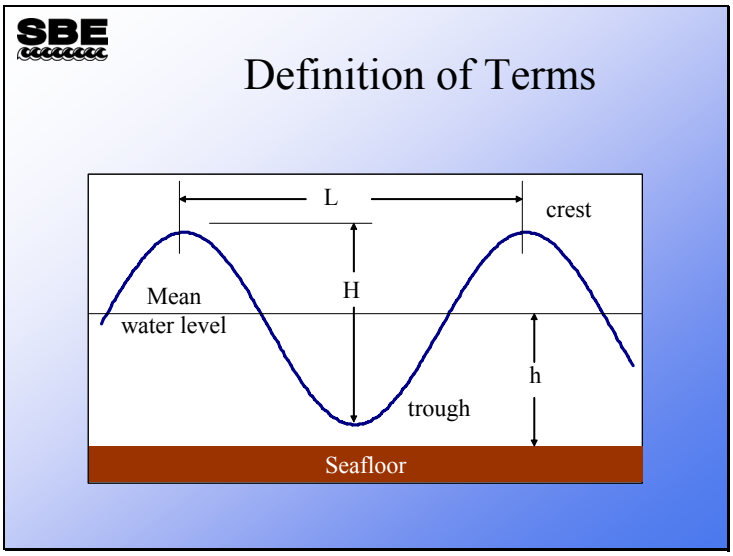


Some of the parameters that we will be able to determine for a wave burst are:

- Average wave height
- Average wave period
- Maximum wave height
- Significant wave height
  - Average height of the highest 1/3 of the waves
- Significant wave period
  - Average period of the highest 1/3 of the waves
- H 1/10
  - Average height of the highest 10% of the waves
- H 1/100
  - Average height of the highest 1% of the waves

It is interesting to note that the significant wave height most closely approximates the wave height reported by trained observers at sea.

Measuring Waves: Background (*continued*)



This slide represents a surface gravity wave with some terms shown.

Where:

L = wave length in meters

H = wave height in meters

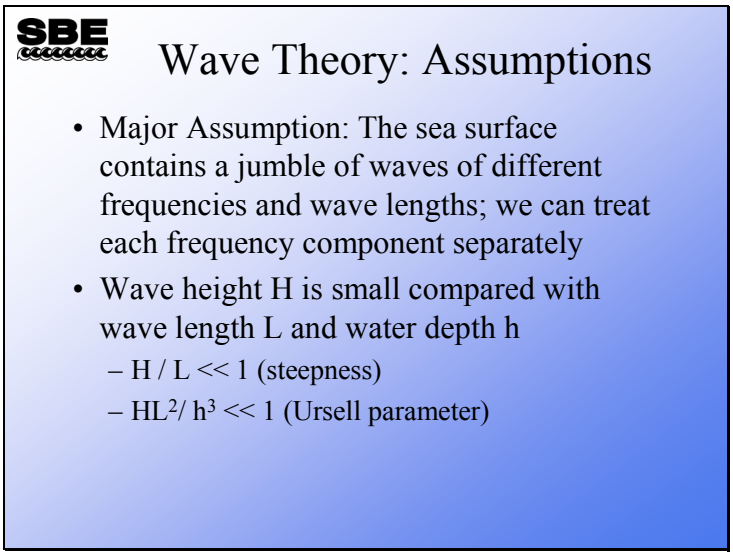
h = water depth in meters

Additional terms:

T = wave period in seconds

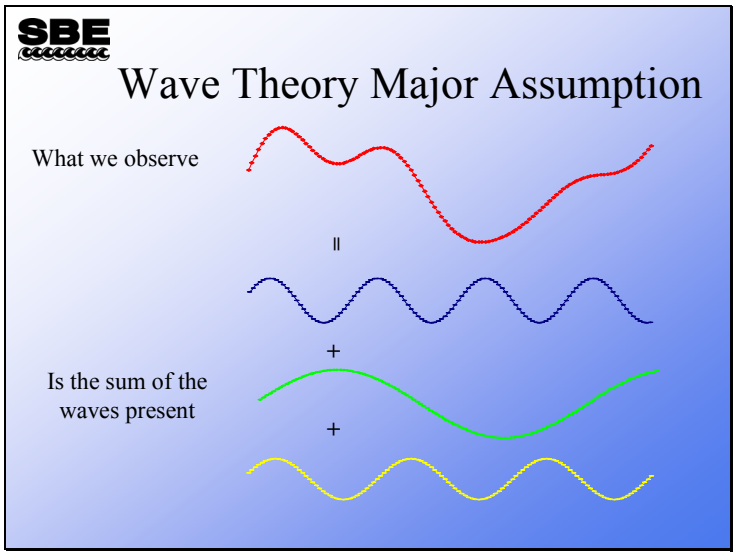
G = 9.80665, acceleration of gravity, m/s^2

Measuring Waves: Background (*continued*)



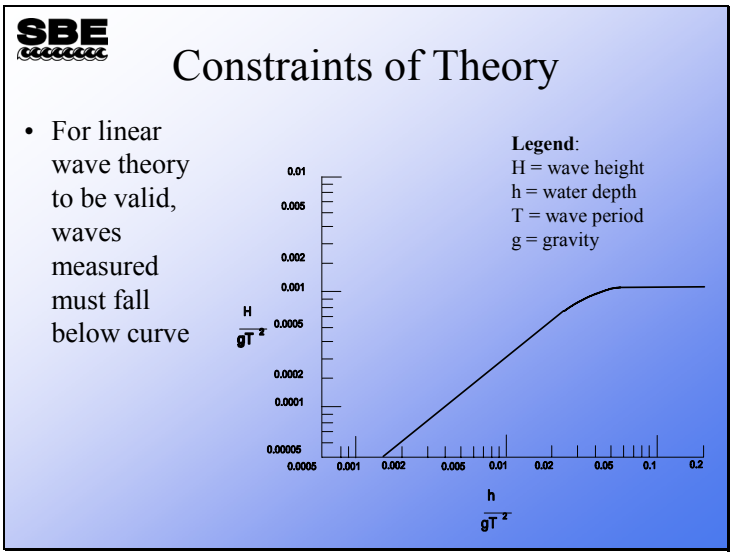
The *major assumption* above is known as linear theory. It supposes that the sea surface we observe is made up of waves of different frequencies, that these waves are superimposed upon one another, and that we can treat each frequency component or wave separately.

Measuring Waves: Background (*continued*)



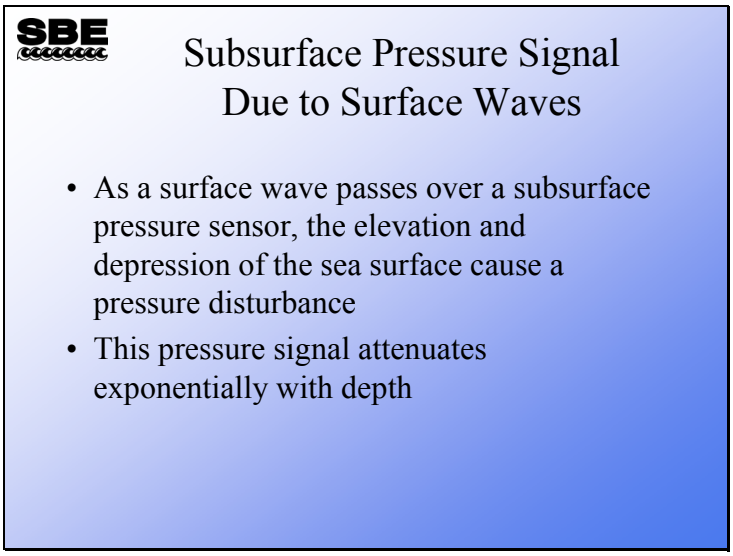
Here is an example of linear theory. The top wave form looks like a sea surface we might observe. It is the sum of the three sinusoids show below it.

Measuring Waves: Background (*continued*)



For the math and the test tanks to work out, the waves we can measure with this technique must fall below the line in the plot. Therefore, we are constrained in what sort of waves we can measure.

Measuring Waves: Background (*continued*)



The technique we use to measure tides and waves is to place a pressure sensor underwater and measure the movement of the sea surface above it. One characteristic of this technique is that the signal is attenuated by the water between the sea surface and the pressure sensor. This attenuation can be mathematically modeled and is called the *dispersion relation*.

Measuring Waves: Background (*continued*)

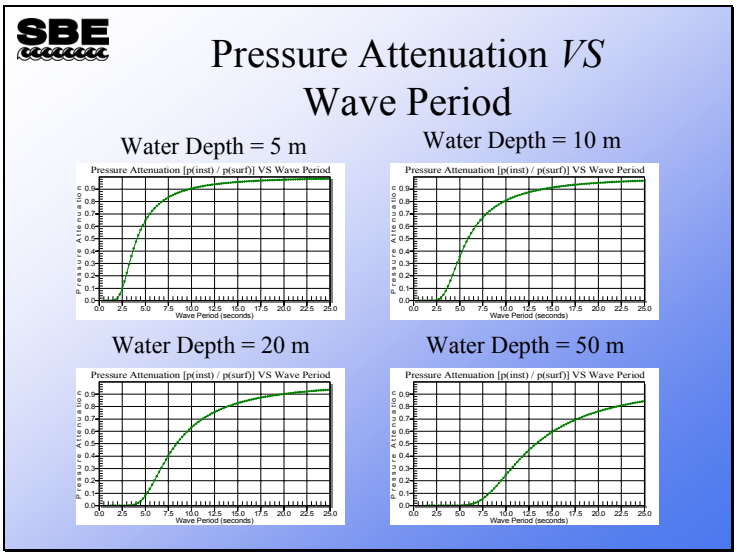
SBE

Pressure Attenuation *vs.* Depth

Depth	Wave Period [seconds]				
[meters]	30	20	10	5	2
2	0.996	0.990	0.960	0.844	0.247
4	0.991	0.980	0.921	0.698	0.036
8	0.982	0.960	0.844	0.448	-----
15	0.967	0.926	0.716	0.171	-----
20	0.956	0.901	0.630	0.079	-----
30	0.934	0.853	0.476	0.016	-----
40	0.912	0.806	0.348	-----	-----
50	0.890	0.760	0.247	-----	-----
75	0.837	0.651	0.096	-----	-----
100	0.786	0.550	0.036	-----	-----

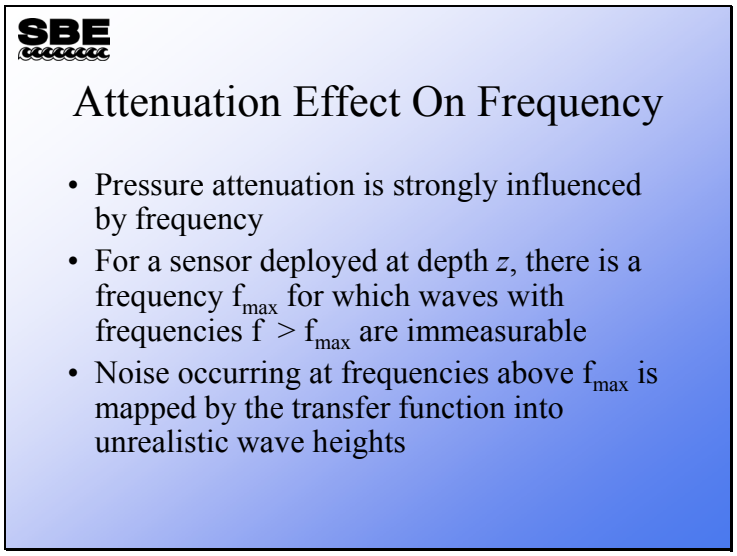
This table was made with the DOS program Wdisp. It shows that the higher the frequency (or the shorter the wave period) that you wish to measure, the closer you have to place your pressure sensor to the surface.

Measuring Waves: Background (*continued*)



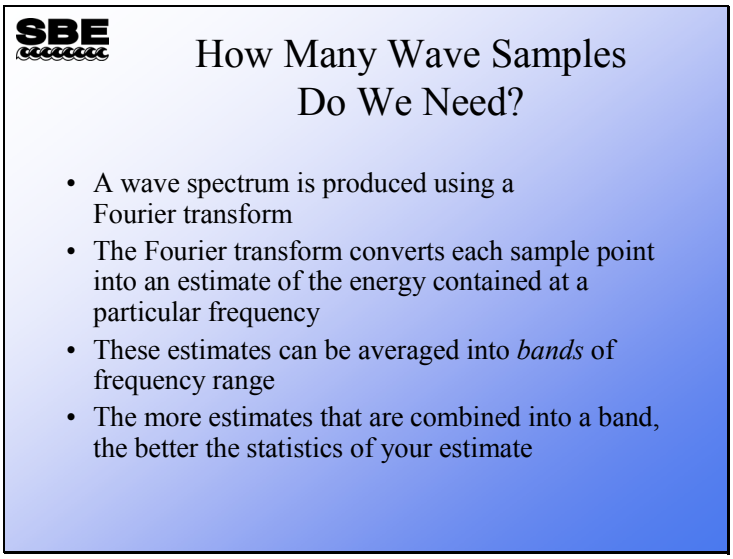
Here are examples of attenuation curves for an SBE 26 or 26*plus* deployed 1 meter off the bottom at 4 different water depths. You can observe that the slope of the curve becomes shallower and that the minimum measurable wave period increases (frequency decreases) as the water depth increases.

Measuring Waves: Background (*continued*)



There is an interesting effect of the dispersion relation on our wave analysis. If you try to measure frequencies that are higher than f_{max}, you will be multiplying the noise measured by the sensor by the inverse of the pressure attenuation. Since the pressure attenuation becomes very small its inverse becomes very big; multiplying noise by a large number makes it appear that you have a lot of wave energy at a high frequency. This artifact in your data can be confusing and is something you should watch for.

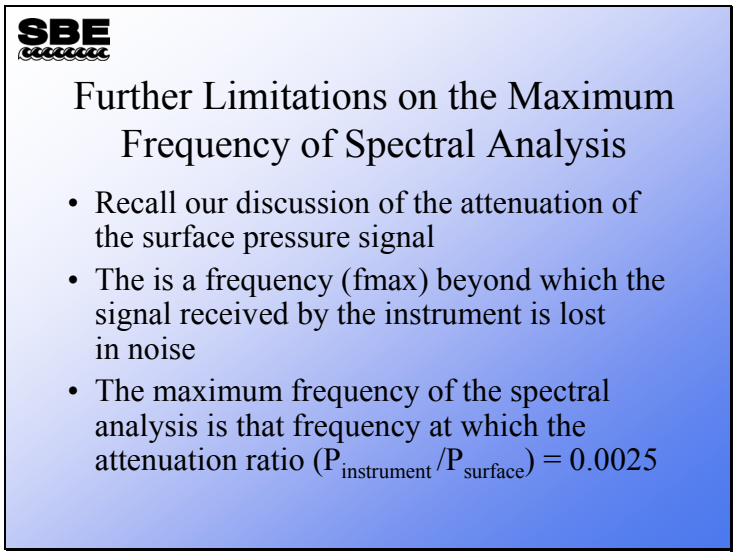
Measuring Waves: Background (*continued*)



The Fast Fourier Transform (FFT) produces an estimate of the energy at each of the data points in the wave burst. The band width of each estimate depends on the sample rate. For a 4 Hz sample rate and 128 points in a wave burst, the band width is 4 / 128 or 0.0313 Hz. Recall the sampling theory, the Nyquist frequency or maximum frequency we can measure is ½ the sample rate. This means that we can only work out to 2 Hz and that only the first 64 data points in our FFT have unique data in them. The points from 64 to 128 are a repeat of the information in points 0 – 63.

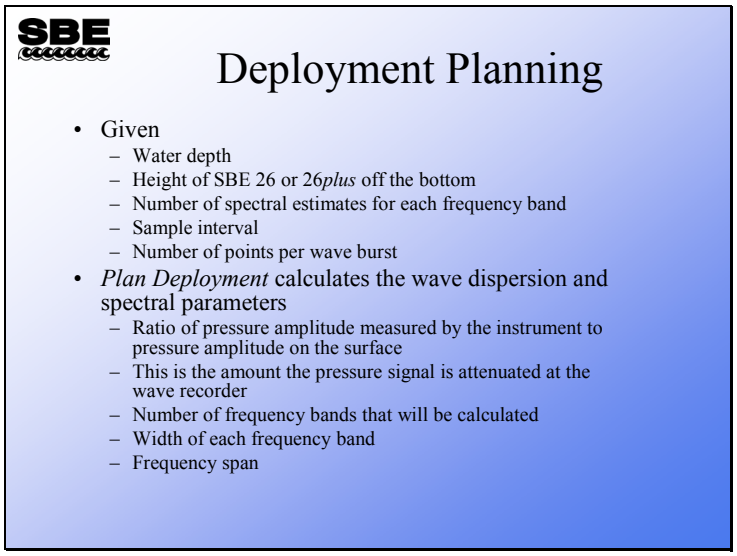
If you lump some of the energy estimates into bands, the average of these estimates provides a more statistically meaningful value.

Measuring Waves: Background (*continued*)



The maximum frequency that we can resolve with our FFT is more severely limited by the attenuation of the pressure signal than by the sampling theory.

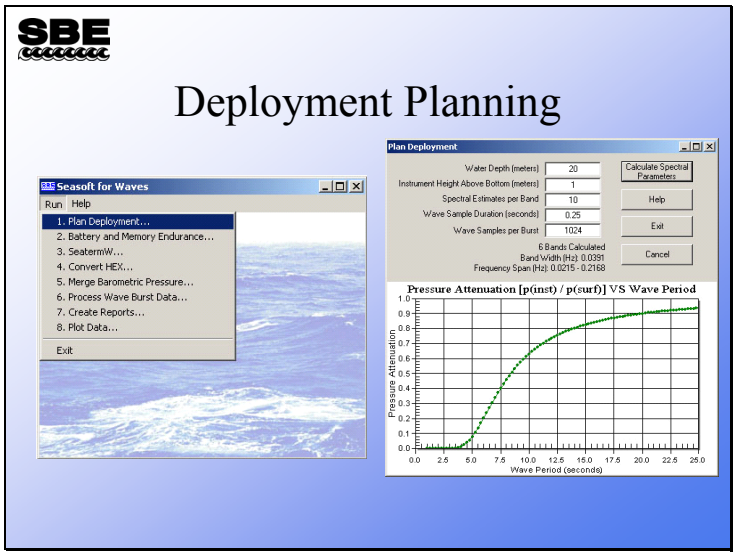
Deployment Planning



This is the first step. *Plan Deployment* tells you the minimum wave period you can detect given the water depth and the height of the SBE 26 or 26*plus* off the bottom. If you know what period of waves you are interested in, you can adjust your instrument placement to successfully measure these. Conversely, if you have no choice in your instrument placement, you can tell ahead of time what the minimum period wave is that you can measure.

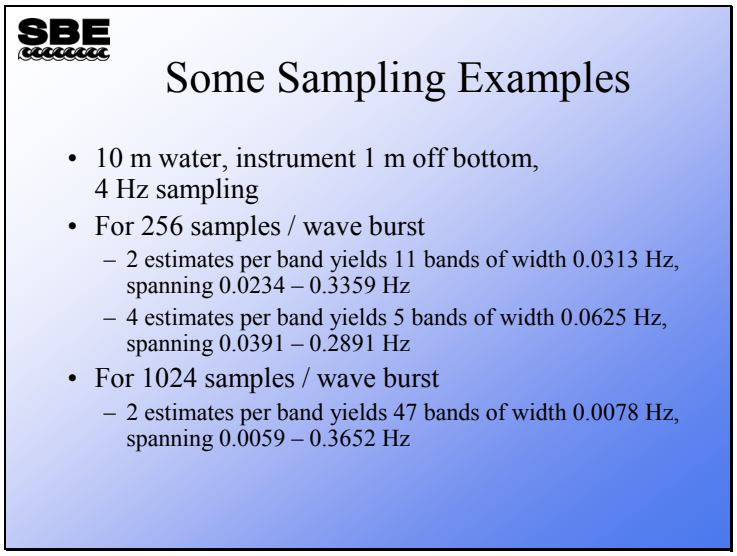
After deciding where you are going to deploy your wave gauge, you have to decide what your sampling protocol is going to be. The sampling protocol determines what the frequency span of your spectral estimate will be, 0 to f_{max}, as well as the number and width of the frequency bands. Recall from our previous discussion that the number of spectral estimates per frequency band determines the statistical quality of the estimate and the width of the frequency bands.

Deployment Planning (*continued*)

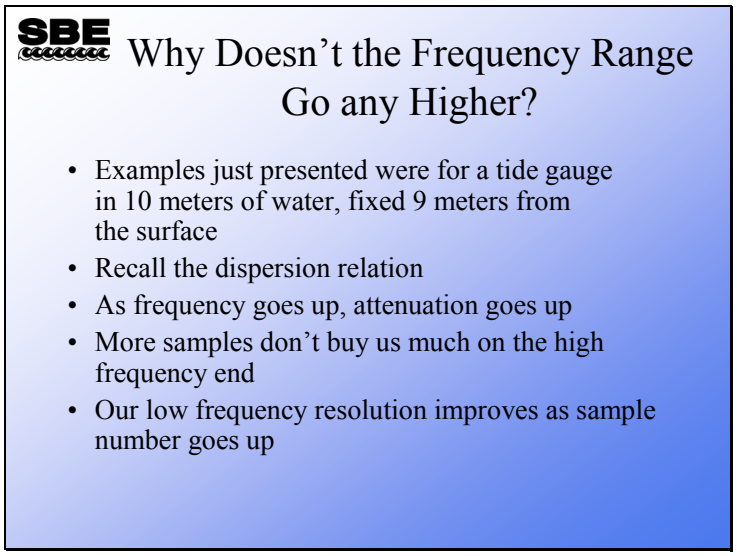


Sea-Bird has special software for use with the SBE 26 and 26*plus* – Seasoft for Waves. *Plan Deployment* and the other software modules we will be talking about are all part of Seasoft for Waves, which you installed from your CD-ROM on the first day of the course.

Deployment Planning (*continued*)

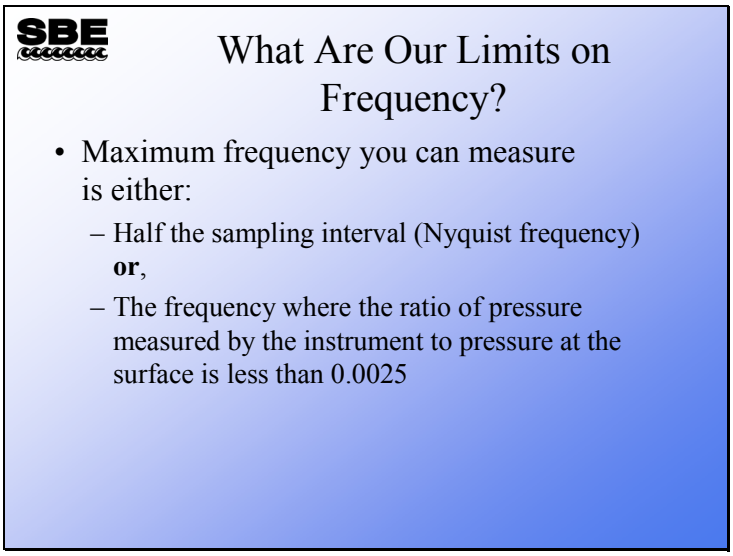


Deployment Planning (*continued*)

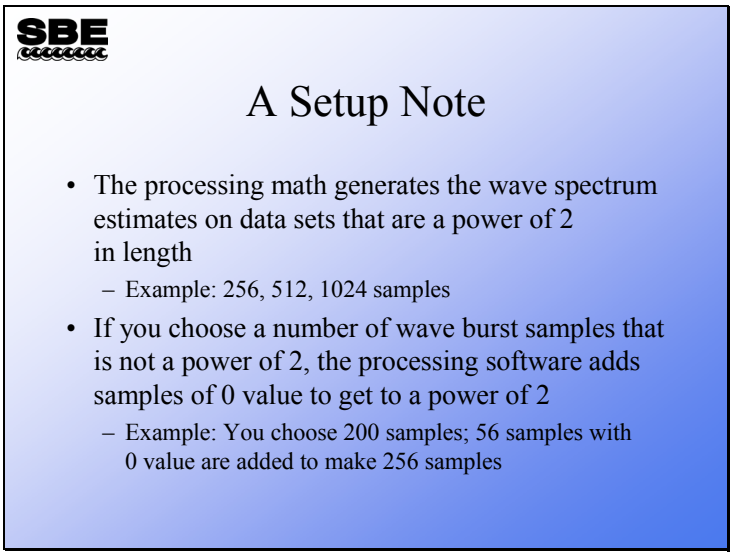


In summary, more samples equals better resolution and better statistics. Your maximum frequency is determined solely by the distance from the sea surface to your instrument and its height off the bottom.

Deployment Planning (*continued*)

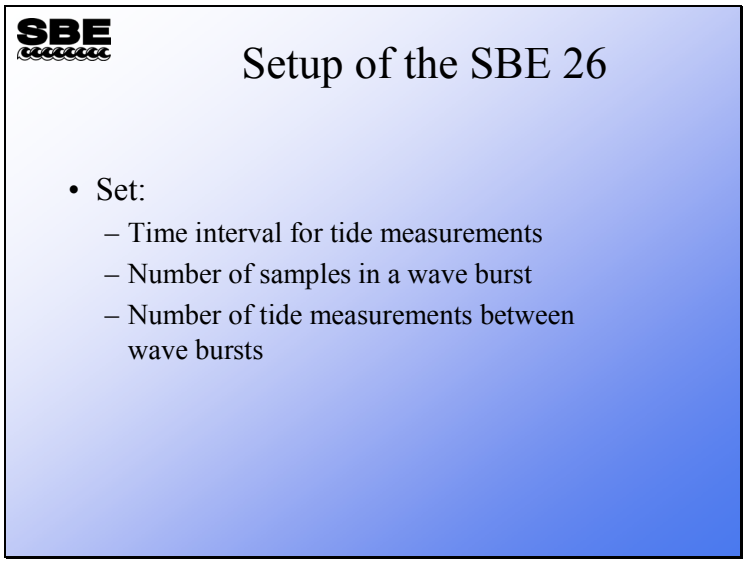


Deployment Planning (*continued*)

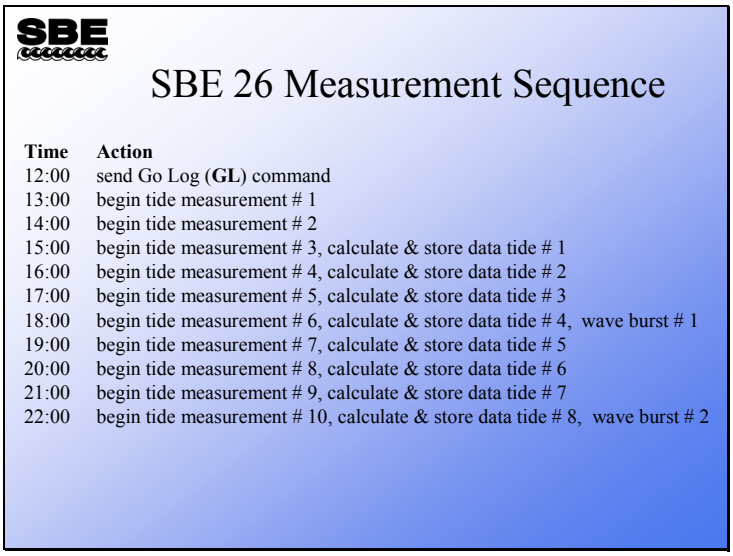


Fast Fourier Transforms are done on data sets that have 2^N elements. If you select a wave burst sample number that is not a power of 2, your data set will be extended to a power of 2 and padded with zeros. While you may save memory this way, you will lose resolution and degrade the statistical confidence you can have in your measurement.

Setting up the SBE 26

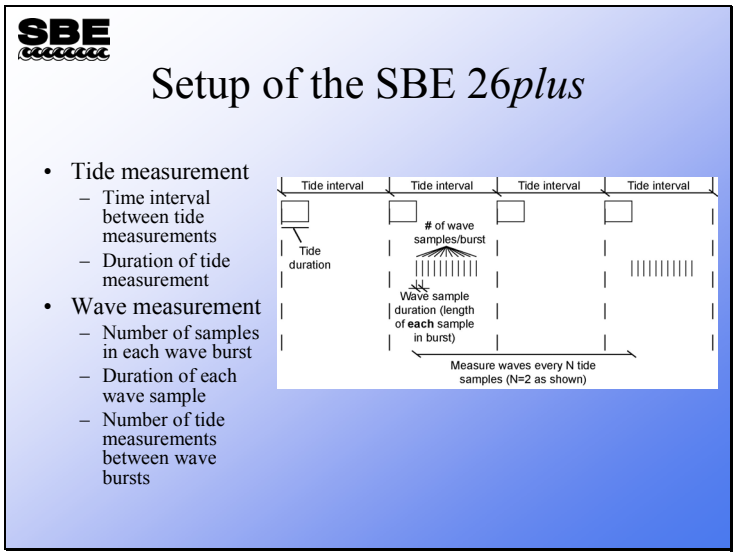


SBE 26 Measurement Sequence



Here is an example measurement sequence for an SBE 26. Tide measurements are an hour in length and a wave burst is done every 4 tide measurements. Because of the frequency counter hardware, a pair of tide measurements is required to calculate the pressure sensed by the SBE 26. Wave bursts are measured after each 4 stored tide measurements.

Setting up the SBE 26*plus*



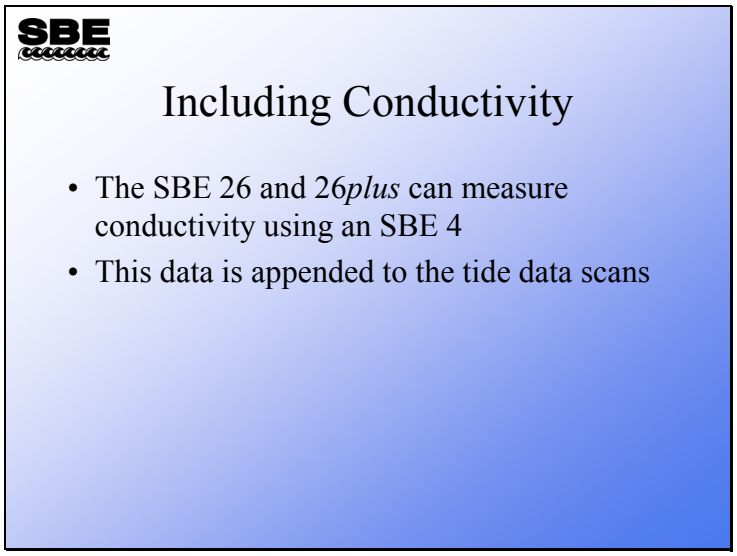
This is just a schematic to illustrate the setup parameters for the SBE 26*plus*. The actual sequencing of the measurements varies, depending on the relationships between the setup parameters.

SBE 26*plus* Measurement Sequence

SBE 26*plus* Measurement Sequence

- Because the SBE 26*plus* has so many more user-selectable parameters than the SBE 26, its measurement sequence is not as straightforward. The sequence varies, depending on:
  - Type of pressure sensor (Quartz or strain gauge)
  - Are you calculating real-time wave statistics? How many samples are you using?
  - Relationship of setup parameters (is there time for wave burst and statistics calculation after tide measurement?)
- Check the manual for examples

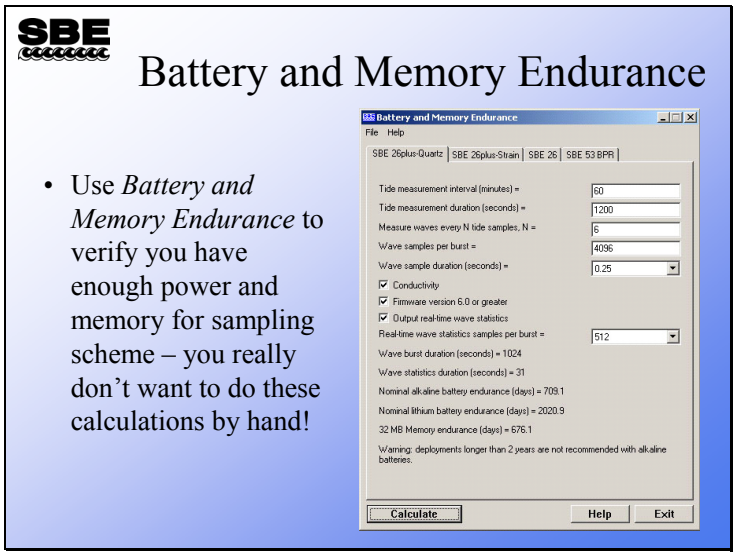
Adding Conductivity



If integrating a conductivity sensor with the SBE 26 or 26*plus*:

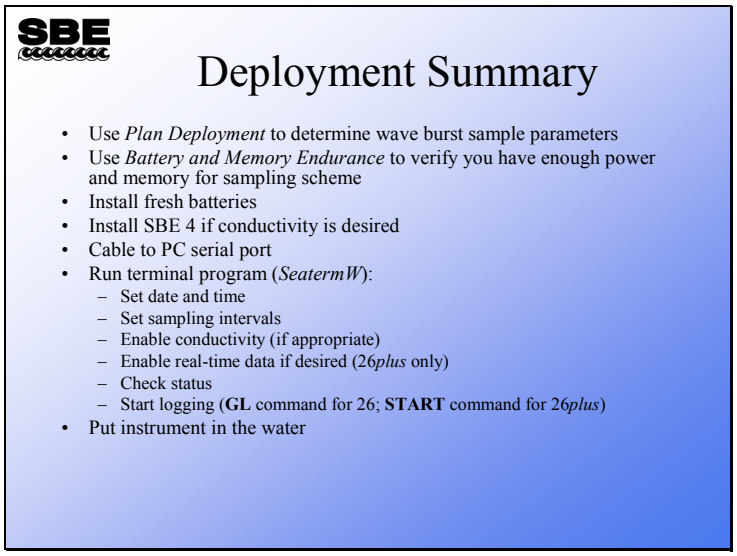
- Connect the conductivity sensor to the instrument's 3-pin bulkhead connector
- Program the instrument to append the conductivity data to the data stream, using the **CY** command in the SBE 26 or the **CONDUCTIVITY=Y** command in the SBE 26*plus*.

Battery and Memory Endurance

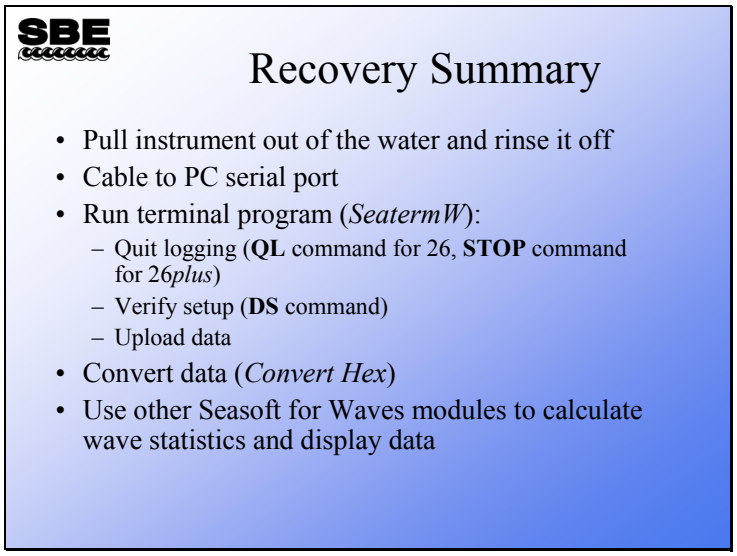


There are separate calculations for the SBE 26 and 26*plus*, and as you can see the 26*plus* is further broken down, depending on the type of pressure sensor. If you are not sure what type of pressure sensor is in your 26*plus*, send the status (**DS**) command in SeatermW; the third line of the response shows the pressure sensor type.

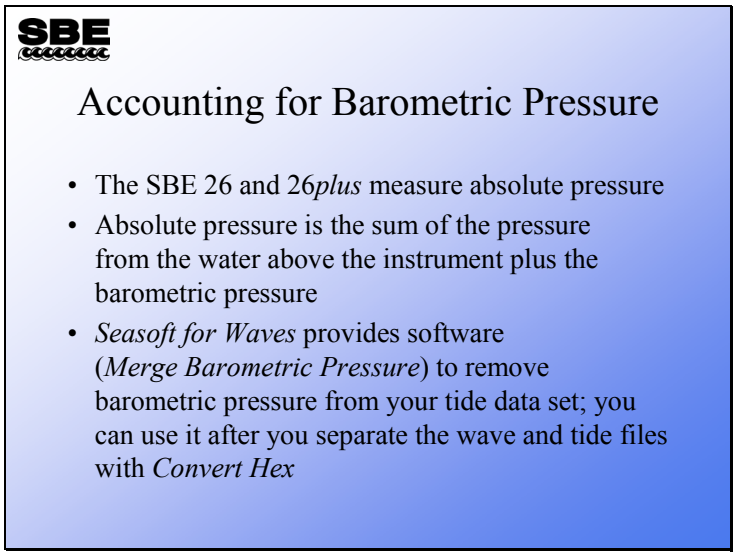
Deployment Summary



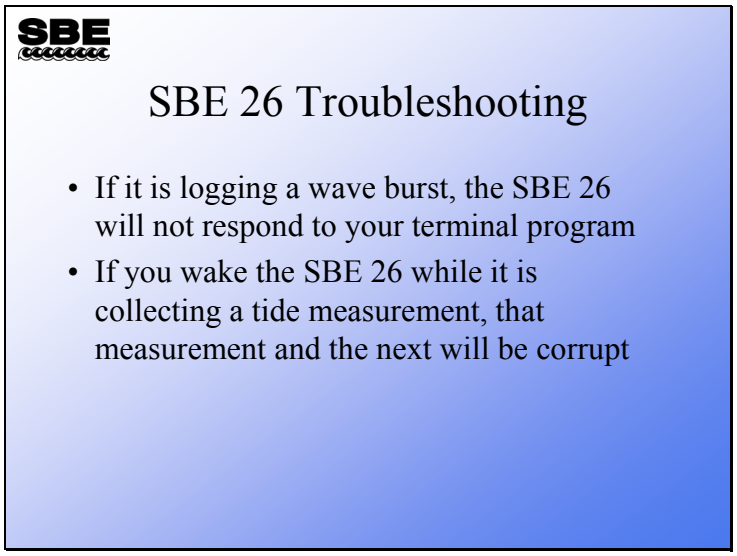
Recovery Summary



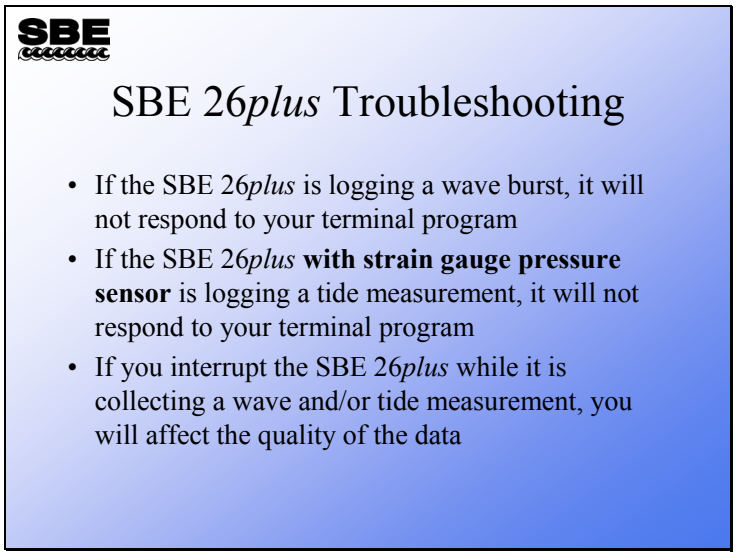
Removing Barometric Pressure from Tide Data



Troubleshooting an SBE 26



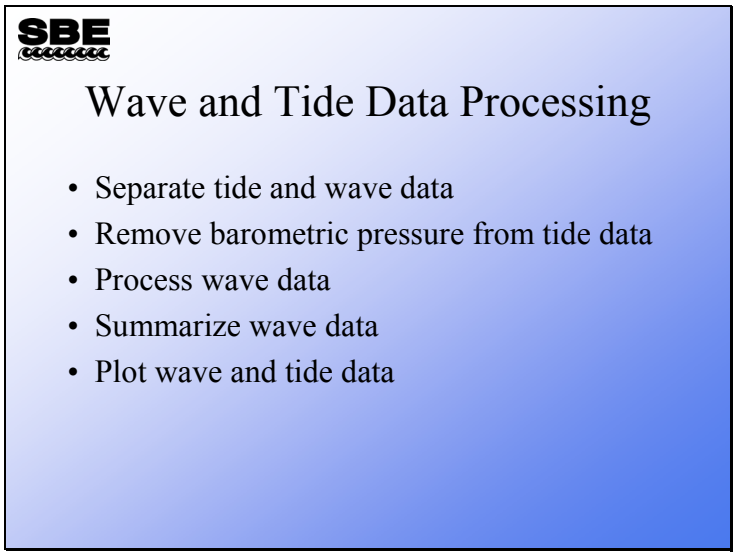
Troubleshooting an SBE 26*plus*



Module 14

Wave and Tide Instruments: Data Processing

Overview

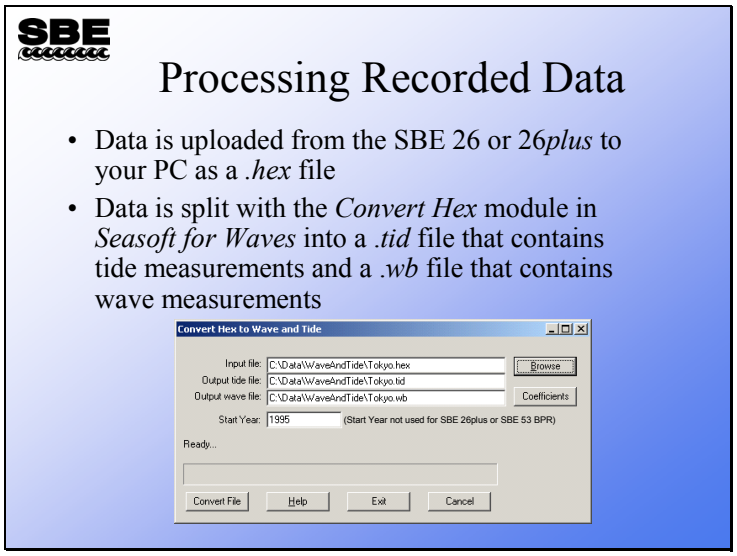


We are going to discuss how to process wave and tide data in our final module. We will work through each of the processing steps with explanations and examples.

By the end of this module you should be able to:

- Process your wave and tide data
- Critically examine your data

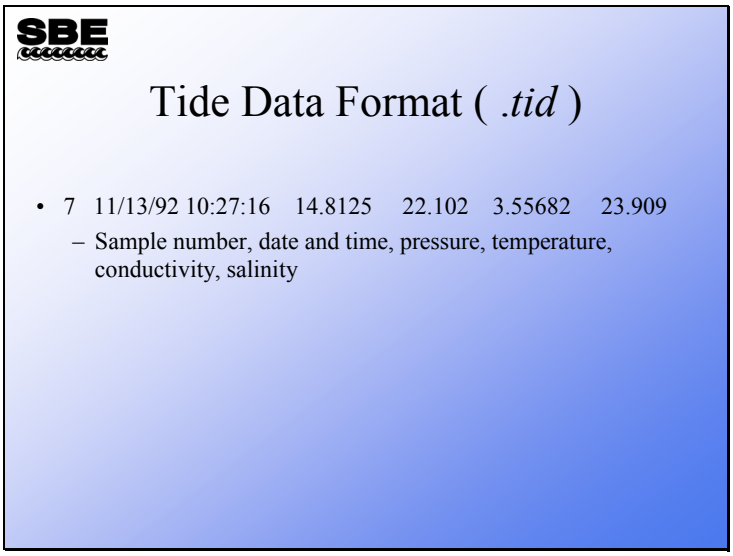
Separating into Wave Data and Tide Data: *Convert Hex*



Data that comes from the SBE 26 or 26*plus* has wave burst data embedded in the tide data. The first step is to split this data (*.hex*) into 2 files (*.tid* and *.wb*).
For the SBE 26, you need to enter temperature calibration coefficients, (optional) conductivity calibration coefficients, and pressure slope and offset (to make small corrections for pressure sensor drift between calibrations). For the SBE 26*plus*, only enter the pressure slope and offset; the other calibration coefficients were programmed into the instrument.

You might notice that the dialog box mentions the SBE 53 BPR (Bottom Pressure Recorder). The SBE 53 measures full ocean depth water level with extremely high resolution, accuracy, and stability. It has some similarities to the SBE 26*plus*, but does not measure waves.

Separating into Wave Data and Tide Data: *.tid* File Format

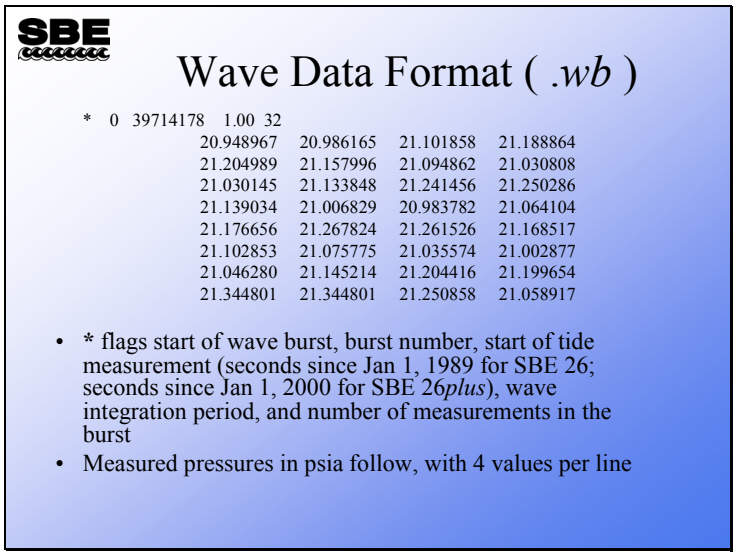


The data format is:

- First column - tide measurement number
- Second and third columns - date and time of the beginning of the tide measurement
- Fourth column - measured pressure in psia
- Fifth column - measured water temperature in °C
- Sixth column - measured conductivity in S/m
- Seventh column - calculated salinity in PSU

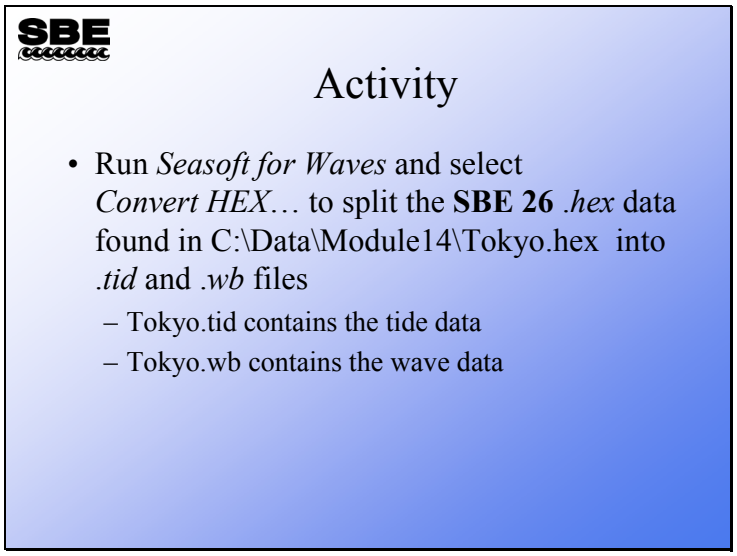
Note that if conductivity logging is not enabled (conductivity = NO in the status display), the sixth and seventh columns of the above table will not be included in the *.tid* file.

Separating into Wave Data and Tide Data: *.wb* File Format



For the SBE 26*plus*, the * line is preceded by a line identifying the data as coming from the 26*plus*, so the software knows that the time is referenced to 2000 instead of 1989.

Activity



Click Start -> Programs -> Sea-Bird ->SeasoftWaves

Click Run -> Convert HEX

Click Browse to select c:\data\module14\tokyo.hex.

Click Coefficients to enter these temperature sensor calibration coefficients:

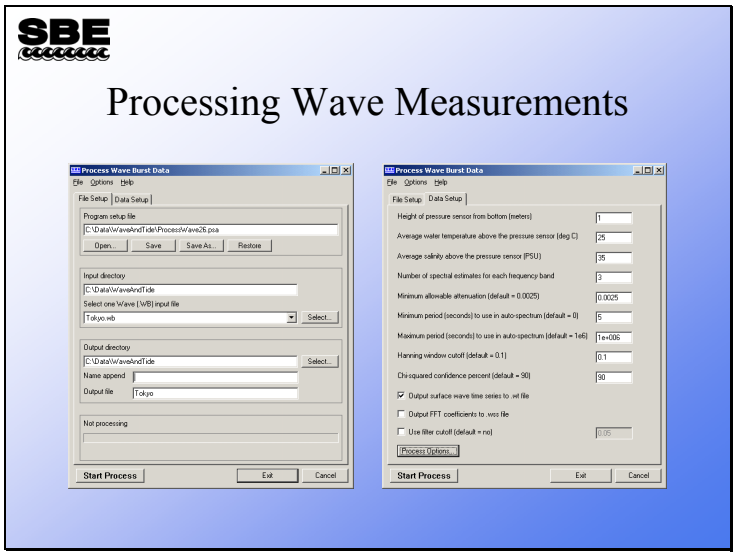
A0 = 9.99463500 E-04
A1 = 2.43988930 E-04
A3 = 1.37995400 E-07

(Note: This example file is from the SBE 26. For the SBE 26*plus*, temperature and conductivity coefficients entered in Convert Hex are ignored. T and C coefficients are programmed into the 26*plus* at Sea-Bird; they can be viewed and modified in SeatermW with user-input commands.)

Enter a Start Year of 1995.

Click Convert File.

Processing Wave Measurements: *Process Wave Burst Data*



Next we are going to process wave bursts. We want to know the wave heights, as well as the frequencies of the waves. Recall from our discussion of linear theory that we assume the observed waves are a combination of several different individual waves. We seek to determine the frequency or period of each of these waves, as well as the amount of energy they have.

The processing application uses the height of the SBE 26 or 26*plus* above the bottom, water temperature, and salinity to determine the density of the water above the instrument.

Output data provides:

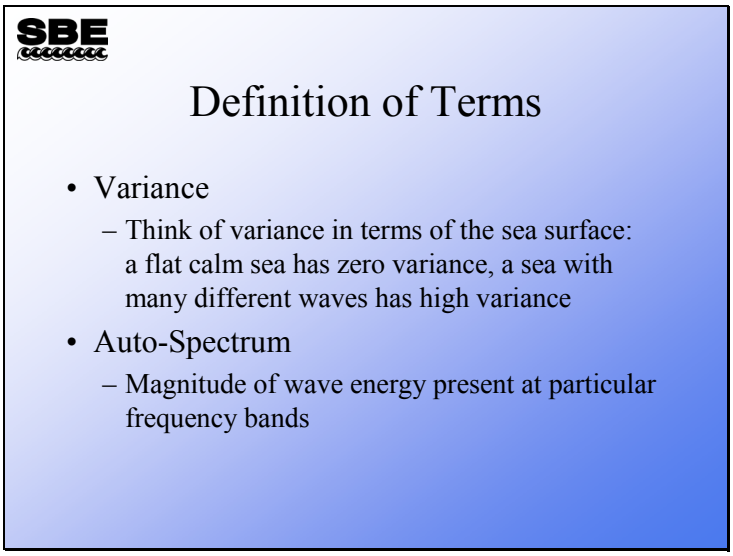
- Auto-spectrum data

  Shows what frequency waves were present by calculating the power or energy present in each of the frequency bands

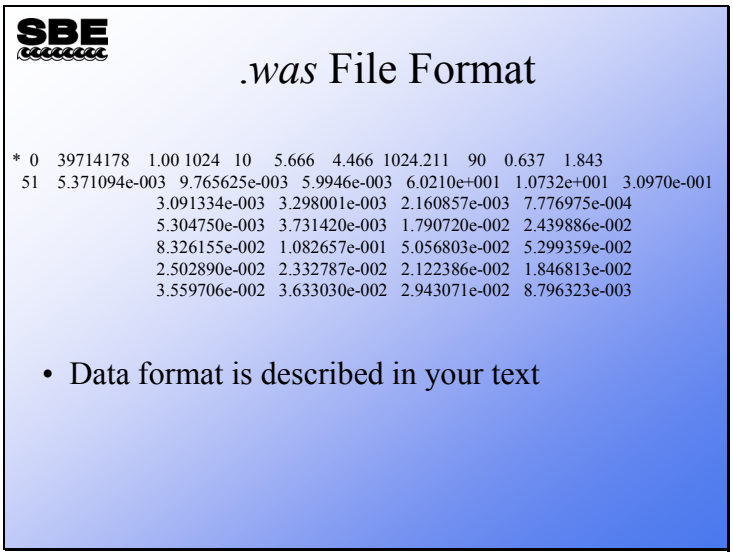
- Time series data

  Shows what the wave heights were and what the actual signal looked like

Processing Wave Measurements: *Process Wave Burst Data* (*continued*)



Processing Wave Measurements: .*was* File Format



Lines beginning with * flag the beginning of the data for a wave burst.

Line 1 contains (in the following order):

burst number
start of wave burst (seconds since Jan 1, 1989 for SBE 26; seconds since January 1 2000 for 26*plus*)
wave integration time (seconds)
number of points in the wave burst
number of spectral estimates for each frequency band
water depth (meters)
pressure sensor depth (meters)
density (kg/m^3)
Chi-squared confidence interval (percent)
multiplier for Chi-squared lower bound
multiplier for Chi-squared upper bound

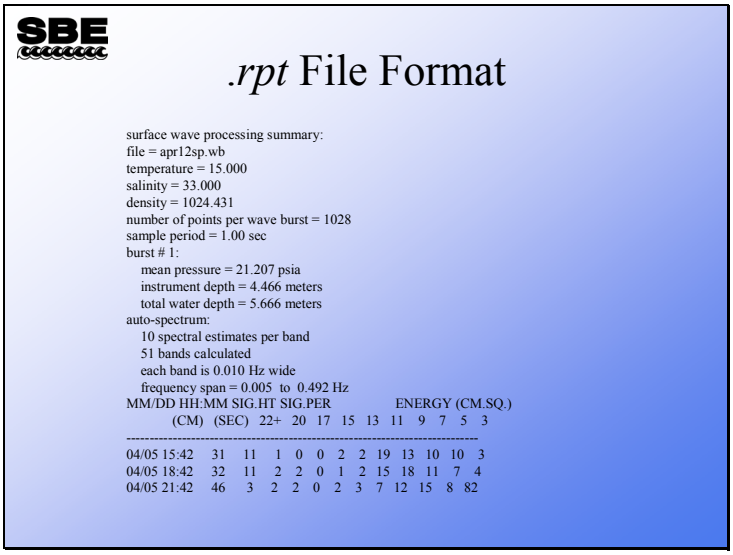
Line 2 contains (in the following order):

number of frequency bands calculated
frequency of the first frequency band (Hz)
interval between frequency bands (delta f) (Hz)
total variance (meters squared)
total energy (Joules / meters^2)
significant period (seconds) = frequency band with the greatest variance
significant wave height (meters) = 4 x sqrt(total variance)

The remaining lines contain the values (beginning with the first frequency) for the Auto-Spectral density function <Gaa>. The units are meters^2 / Hz. To obtain the variance (m^2) in a frequency interval delta f (Hz), multiply the value of <Gaa> by delta f.

Once again, for the SBE 26*plus*, the * line is preceded by a line identifying the data as coming from the 26*plus*, so the software knows that the time is referenced to 2000 instead of 1989.

Processing Wave Measurements: *.rpt* File Format



The energy (cm^2) is the sum of the variance over the indicated frequency band:

The 9 second wave period column is the sum of the variances where the frequency is between 1/10 Hz and 1/8 Hz.

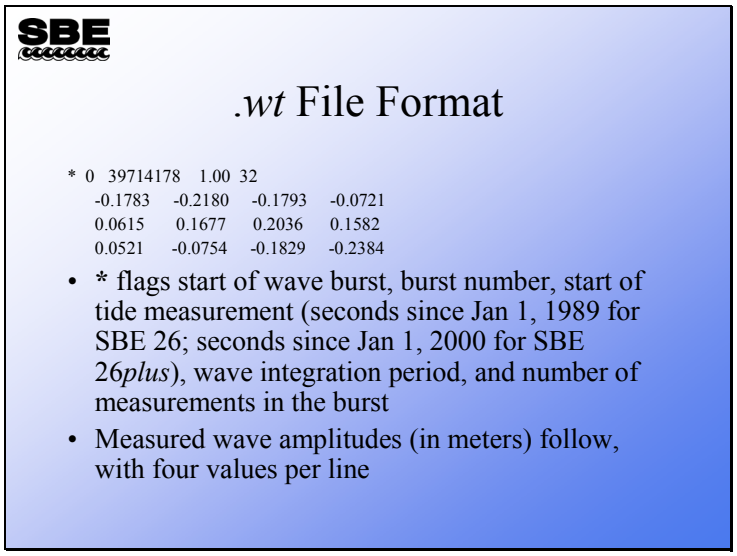
The 20 second wave period column is the sum of the variances where the frequency is between 1/22 Hz and 1/18 Hz.

The 22+ second wave period column is the sum of the variances of all the frequencies less than 1/22 Hz.

Significant period is:

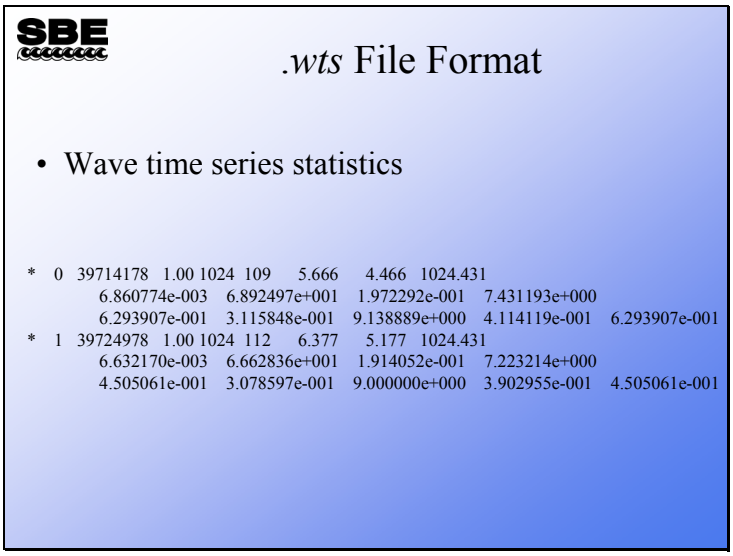
1 / (band averaged frequency with the greatest variance)

Processing Wave Measurements: .*wt* File Format



Once again, for the SBE 26*plus*, the * line is preceded by a line identifying the data as coming from the 26*plus*, so the software knows that the time is referenced to 2000 instead of 1989.

Processing Wave Measurements: .*wts* File Format



Lines beginning with * flag the beginning of the data for a wave burst.

Line 1 contains (in the following order):

burst number
start of wave burst (seconds since January 1, 1989 for SBE 26; seconds since January 1, 2000 for SBE 26*plus*)
wave integration time in seconds
number of points in the wave burst
number of individual waves found
water depth (meters)
pressure sensor depth (meters)
density (kg/m^3)

Line 2 contains (in the following order):

total variance of the time series ($meters^2$)
total energy of the time series ($Joules/meters^2$)
average wave height (meters)
average wave period (seconds)

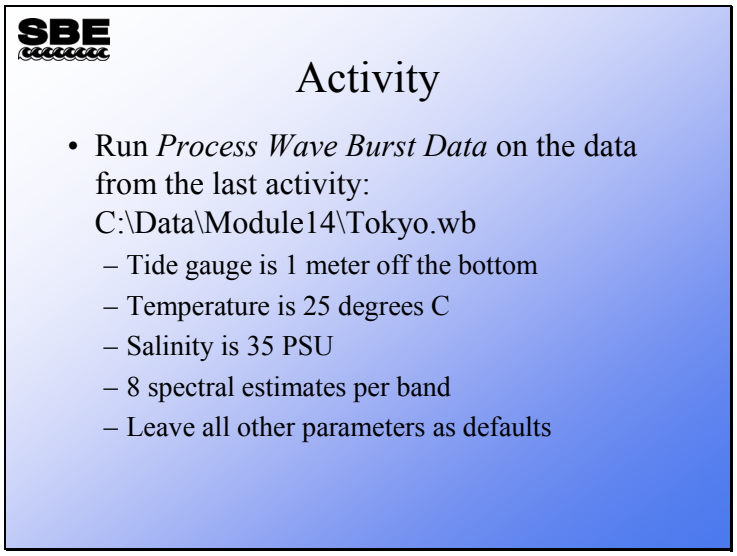
Line 3 contains (in the following order):

maximum wave height (meters)
significant wave height (meters) = average height of the largest 1/3 waves
significant period (seconds) = average period of the largest 1/3 waves
$H_{1/10}$ (meters) = average height of the largest 1/10 waves
$H_{1/100}$ (meters) = average height of the largest 1/100 waves

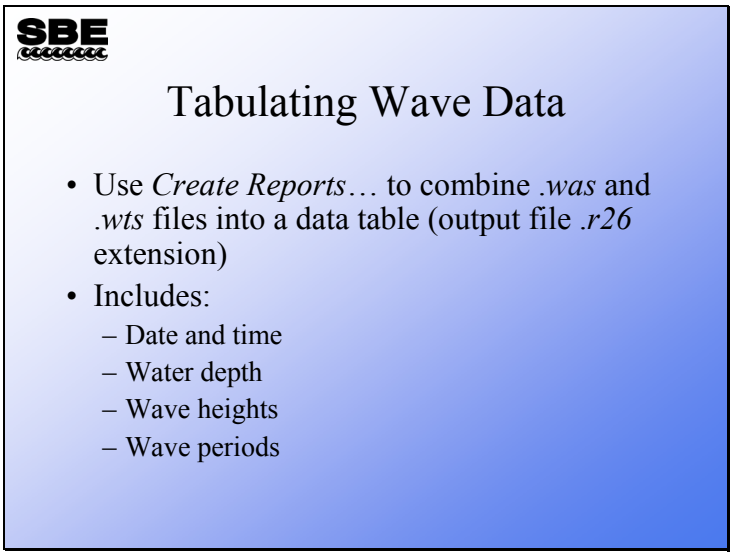
If there are less than 10 waves, $H_{1/10}$ is set to 0.
If there are less than 100 waves, $H_{1/100}$ is set to 0.

Once again, for the SBE 26*plus*, the * line is preceded by a line identifying the data as coming from the 26*plus*, so the software knows that the time is referenced to 2000 instead of 1989.

Activity


SBE
Activity
• Run *Process Wave Burst Data* on the data from the last activity: C:\Data\Module14\Tokyo.wb
– Tide gauge is 1 meter off the bottom
– Temperature is 25 degrees C
– Salinity is 35 PSU
– 8 spectral estimates per band
– Leave all other parameters as defaults

Tabulating Wave Data: *Create Reports*



Below is the file format for an *.r26* file. This file is the combination of *.was* and *.wts* files.

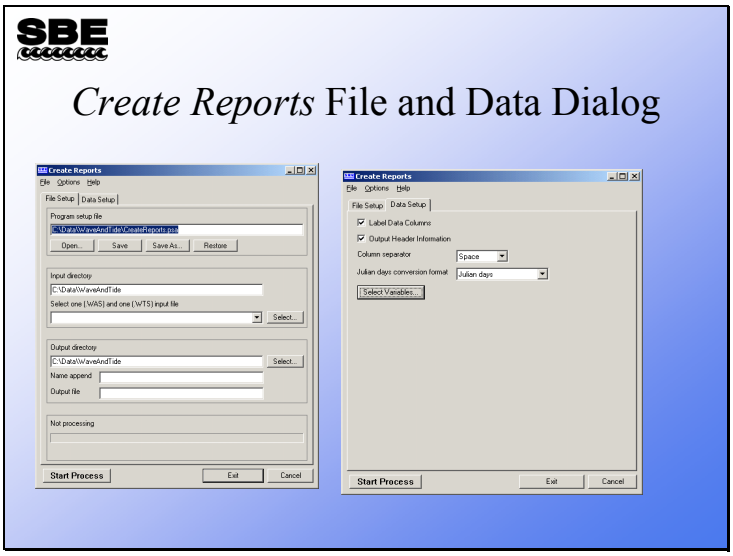
- From Surface Wave Time Series Statistics:

variable	**column label**
time	time
burst number	burst
pressure sensor depth	depth
number of waves	nwaves
variance	var-wts
energy	energy-wts
average wave height	avgheight
average wave period	avgper
maximum wave height	maxheight
significant wave height	swh-wts
significant wave period	swp-wts
$H_{1/10}$	H1/10
$H_{1/100}$	H1/100

- From Wave Burst Auto-Spectrum Statistics:

variable	**column label**
variance	var-was
energy	energy-was
significant wave height	swh-was
significant wave period	swp-was

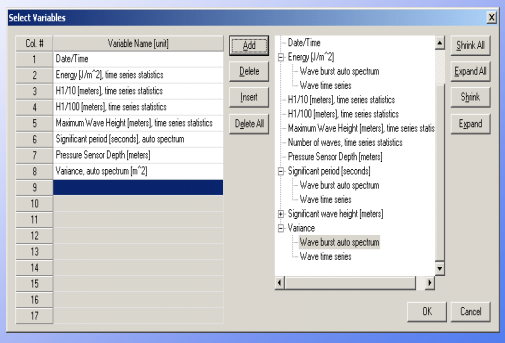
Tabulating Wave Data: *Create Reports* (*continued*)



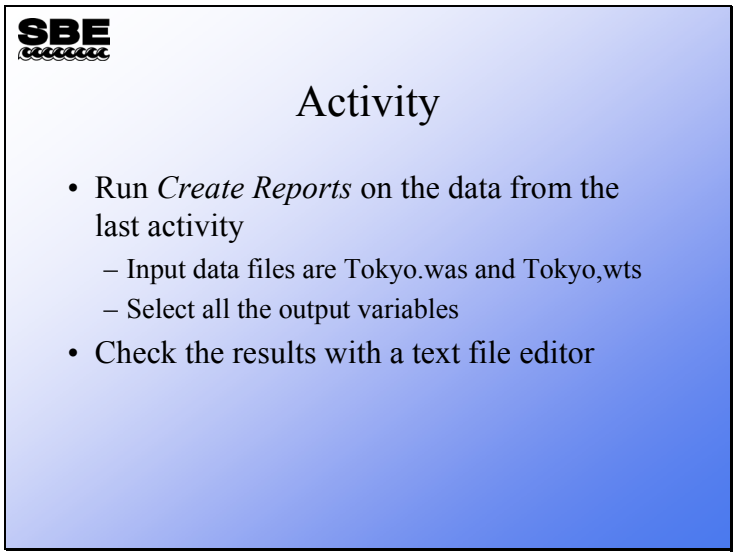
Tabulating Wave Data: *Create Reports* (*continued*)

Create Reports Variable Menu

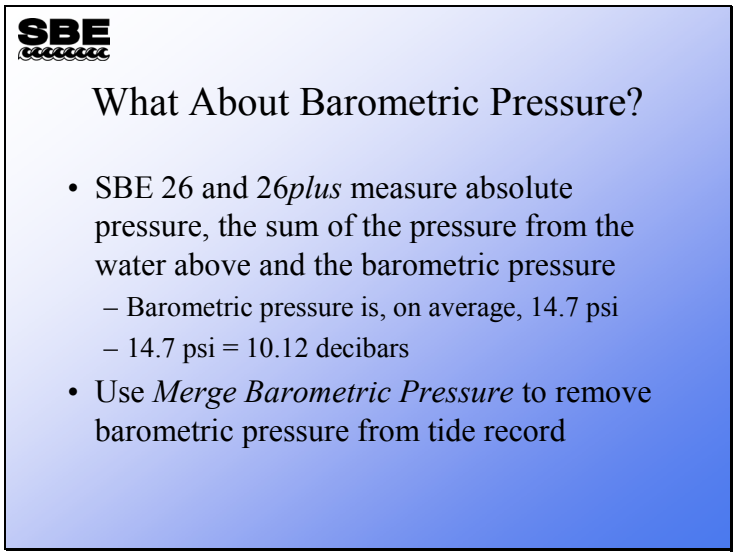
- Enter the variables in the order that is useful to you



Activity


SBE
Activity
• Run *Create Reports* on the data from the last activity
– Input data files are Tokyo.was and Tokyo,wts
– Select all the output variables
• Check the results with a text file editor

Removing Barometric Pressure from Tide Data: *Merge Barometric Pressure*

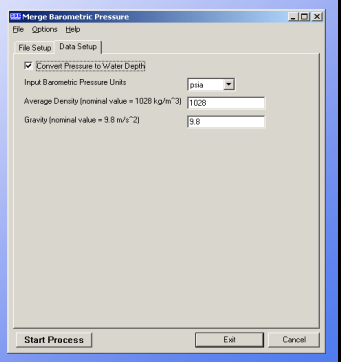


In some places, particularly micro tidal places, barometric pressure can be a significant part of the tidal signal. The *Merge Barometric Pressure* module allows you to input a time-stamped barometric data set and remove the barometric pressure from your tide measurement. The input data for *Merge Barometric Pressure* is date, time, and pressure in millibars or psia.

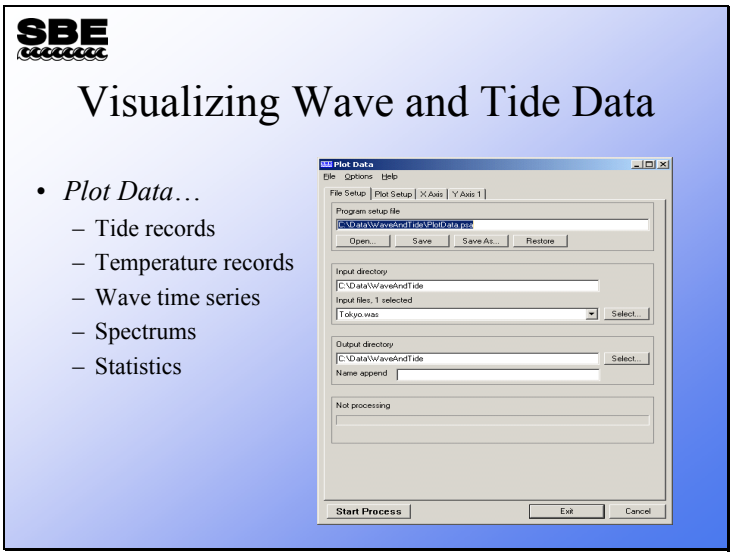
Removing Barometric Pressure from Tide Data: *Merge Barometric Pressure* (*continued*)

Merge Barometric Pressure Data Setup Dialog

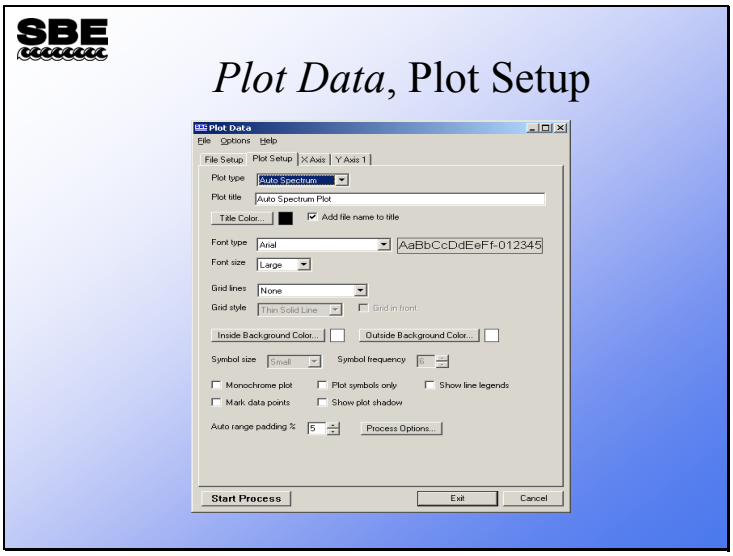
- Barometric pressure file has to have *.bp* extension
- File format is Date Time Pressure (psia or millibars):
  - MM/DD/YY HH:MM:SS P
- Times in .bp and .tid files do not need to be aligned
  - Software uses linear interpolation to align data in .bp file in time to .tid data before subtracting barometric pressure



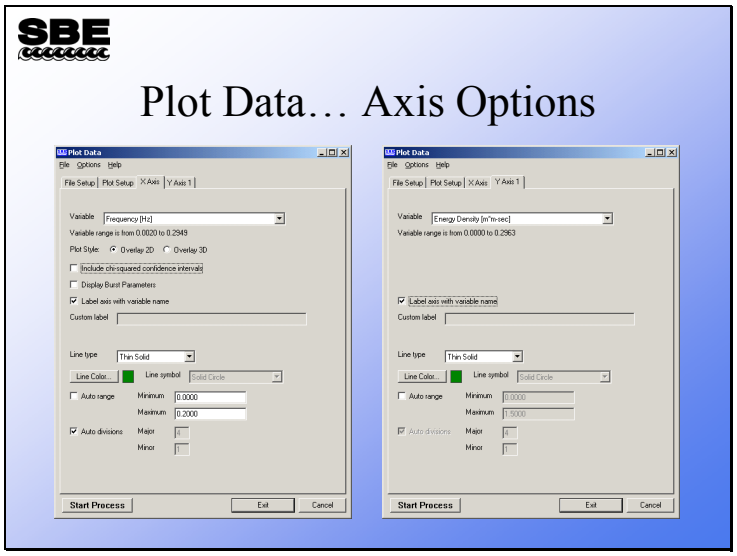
Graphing Wave and Tide Data: *Plot Data*



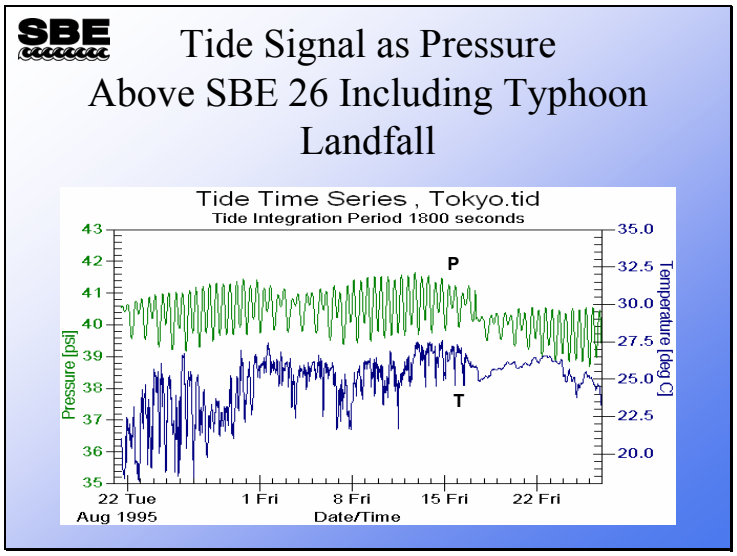
Graphing Wave and Tide Data (*continued*)



Graphing Wave and Tide Data (*continued*)



A Wave and Tide Example



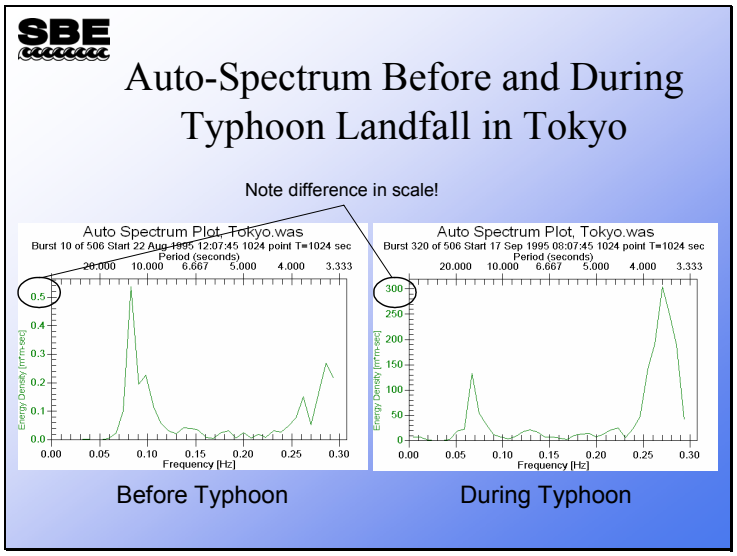
Our example data comes from Tokyo harbor. During this deployment a typhoon made landfall. In this deployment the SBE 26 was fixed in 18 meters of water and was 1 meter off the bottom. Wave bursts were 600 samples long (Why would this be a silly thing to do?).

The green line is the pressure (tide) signal. Note that when the Typhoon comes ashore there is a disruption in the normal tidal cycle, and the pressure above the 26 drops. What could cause the mean water height to suddenly become lower after the typhoon?

The blue line is the temperature recorded by the SBE 26 before and after the typhoon comes in. Note that in this plot the tidally influenced temperature signal all but disappears after the storm.

The answer to what is going on is that the platform to which the SBE 26 was attached was moved into shallower water by the typhoon. Will this movement influence the wave spectrum estimates?

A Wave and Tide Example (*continued*)

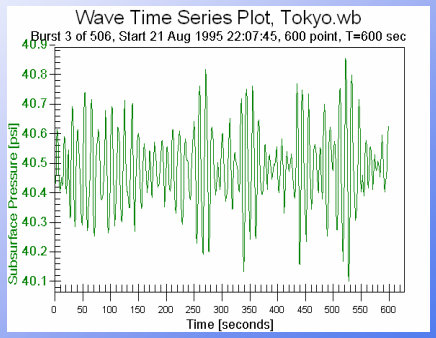


The auto-spectrum plots clearly show the arrival of longer period waves of considerably higher energy.

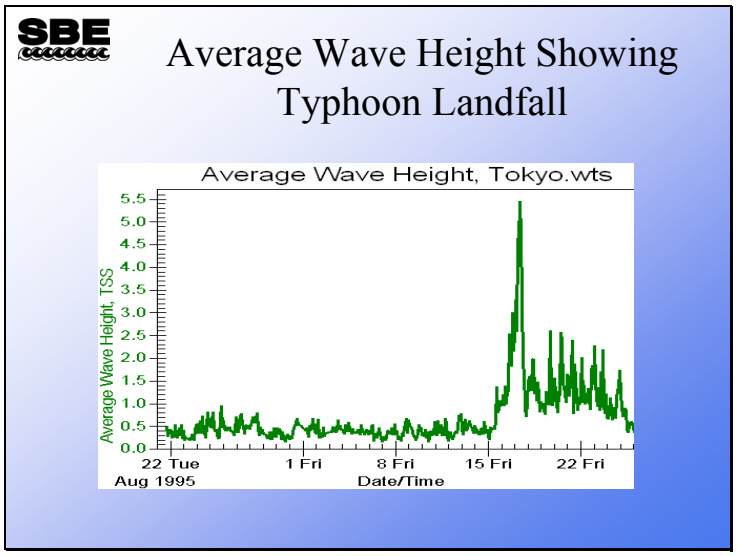
A Wave and Tide Example (*continued*)

Wave Burst Time Series

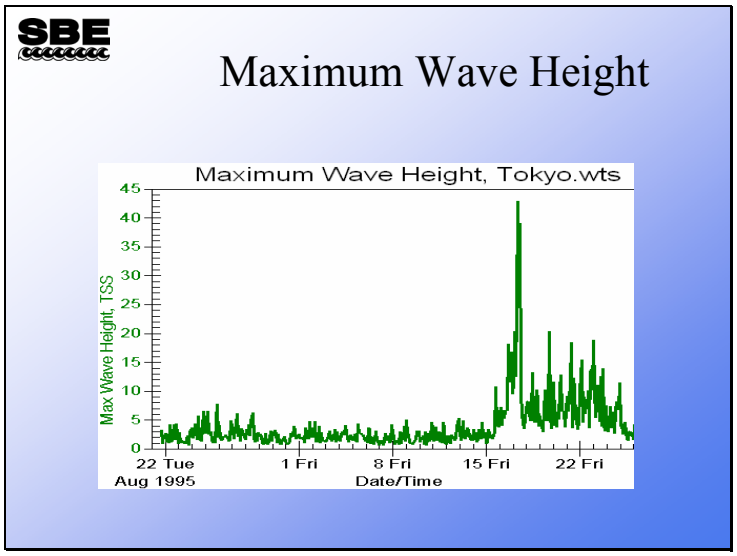
- This is the actual pressure data collected during a wave burst before the typhoon



A Wave and Tide Example (*continued*)

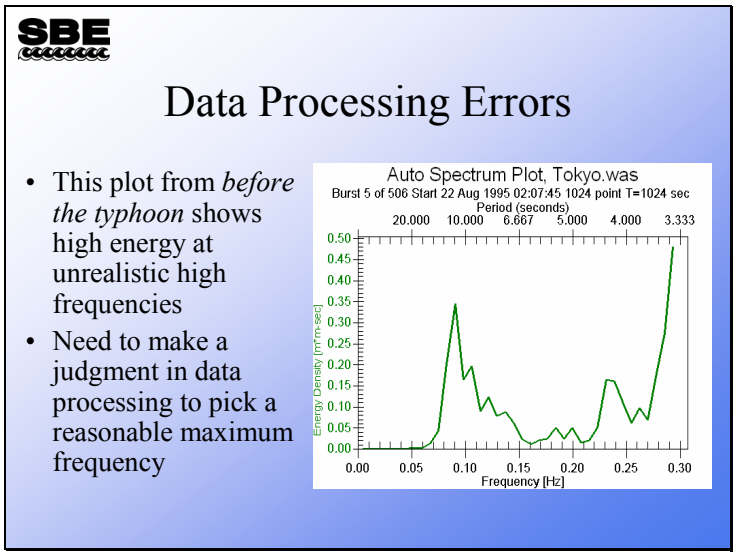


A Wave and Tide Example (*continued*)



Here are the maximum wave heights. See anything funny going on here?

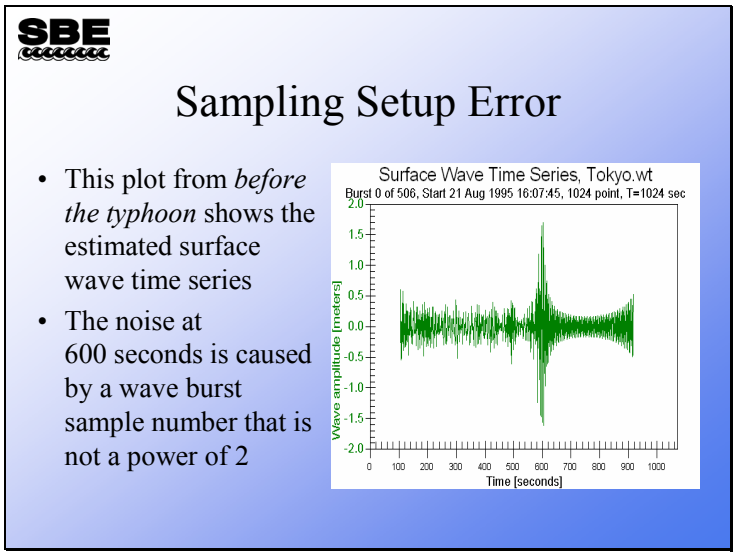
A Wave and Tide Example, Processing Errors



If you look at the entire auto-spectrum, you will often find a large signal at the end of the plot. This is usually an artifact in the data that is caused by the dispersion relation. The calculated attenuation coefficient is erroneously applied to noise, causing the appearance of high energy at high frequencies.

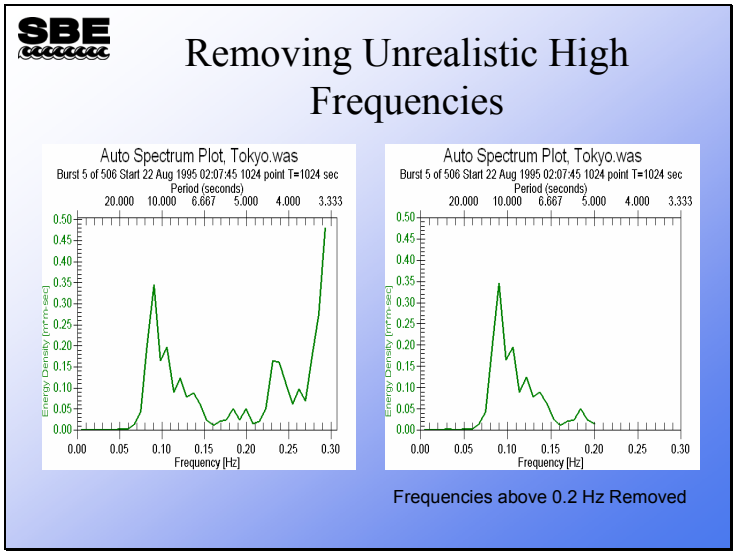
The artifact can be removed by setting the *Minimum period to use in autospectrum* to a reasonable value. You can test this by processing your data with and without the *Minimum period* and comparing autospectrum and the surface wave time series.

A Wave and Tide Example, Sampling Setup Errors



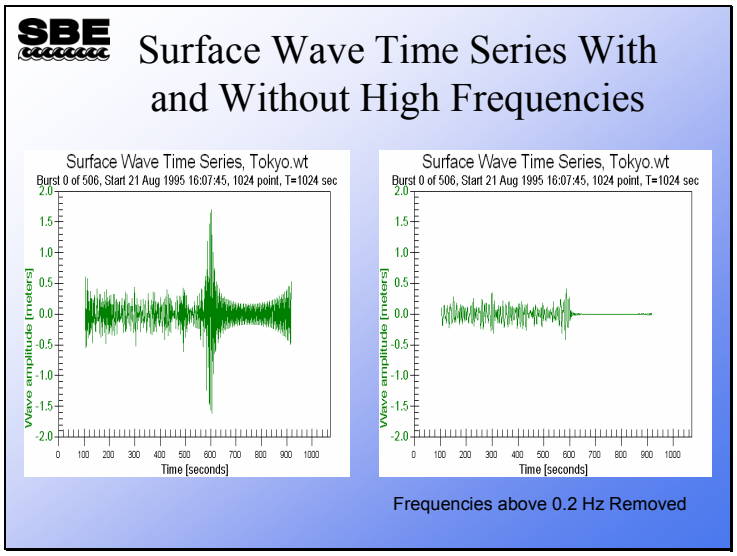
This is an interesting plot. Recall that when we were looking at the plots earlier, the wave burst sample size of 600 points was mentioned. Also recall that wave burst data must have a number of samples that is a power of 2. If the number of samples is not a power of 2, it is padded with the mean water level out to a power of 2. You can see that there is a disturbance in the plot around the 600-second mark and diminished magnitude after it. This is a processing artifact due to the mismatched burst size and high frequency noise being interpreted as wave signal.

A Wave and Tide Example, Correcting Processing Errors



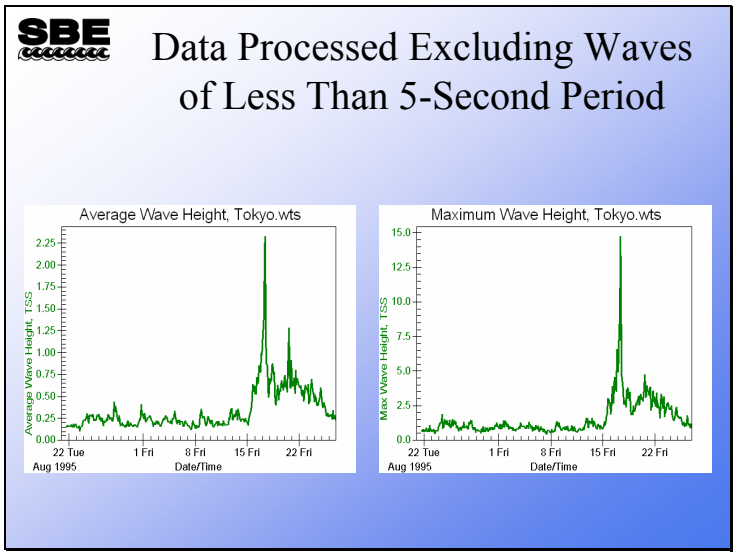
In the plot on the right we have removed all data with period shorter than 5 seconds (corresponding to a frequency of 0.2 Hz). Note that the auto-spectrum shows energy in mainly one frequency band and seems much more believable.

A Wave and Tide Example, Correcting Processing Errors



Removing the high frequency (noise) component of the signal also cleans up the surface wave time series. In the plot on the right, the data artifact beginning at the point where the data is padded to make a power of 2 number of samples is suppressed.

Processing Wave Data: Reality Check



We've recalculated average wave height and maximum wave height, after removing wave periods less than 5 seconds (frequencies greater than 0.2 Hz). These are much more believable than the previous plots.

Activity

SBE
Activity
• Check out your auto-spectrum and time series data with *Plot Data*