Module 12

Getting the Highest Accuracy Data from Moored Instruments

Overview

Getting the Highest Accuracy Data: Moored

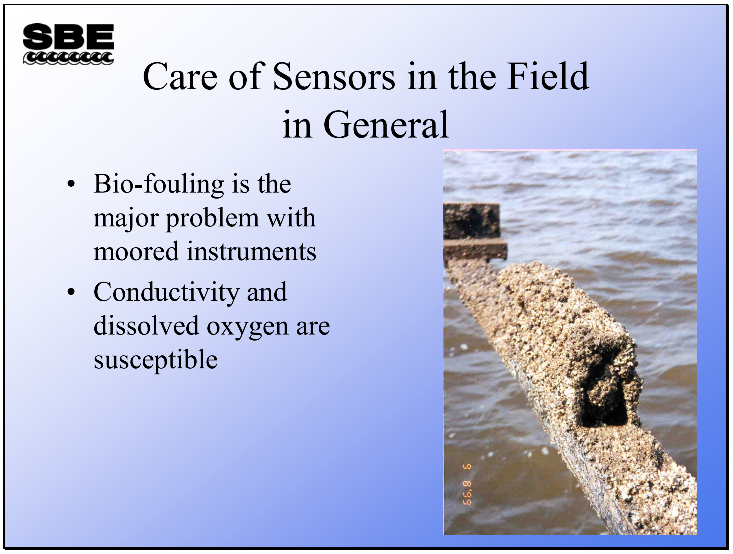
- Care of sensors in field
- Bio-fouling
- Data example
- Sensor drift characteristics
- Pre- and post-deployment calibrations
- Field calibrations

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:

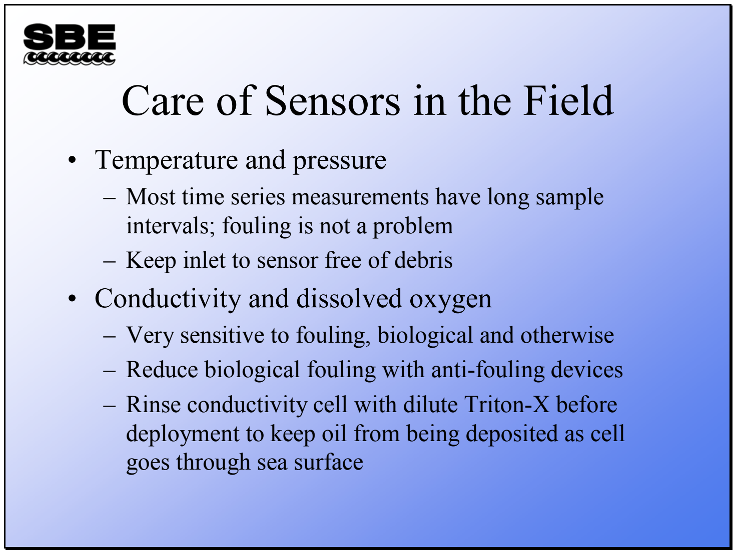
- Care for your moored sensors
- Know how to reduce bio-fouling
- Understand sensor drift
- Correct data for sensor drift with pre- and post-calibration
- Compare data from your mooring with data collected with a profiling instrument

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

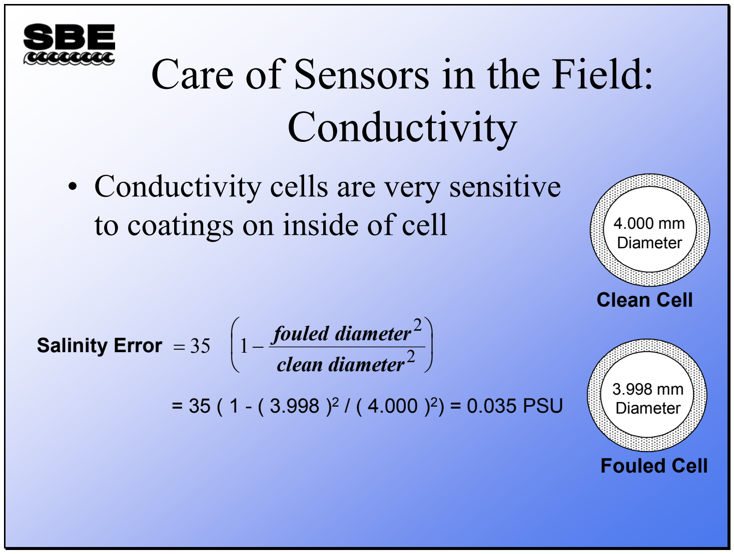


As we have discussed, thermometers are very robust. In moored applications, the sampling interval is much longer than the time constant of the thermometer, so except in extreme conditions fouling does not affect thermometers.

Occasionally, when a Sea-Bird instrument with a Druck pressure sensor is deployed in a muddy and/or biologically productive environment, the pressure port may partially fill with sediment or the pressure port plug vent hole may be covered with biological growth. Either of these occurrences can cause a delay in the pressure response, or in extreme cases can completely block the pressure signal. Sea-Bird developed a high-head pressure port plug for these types of deployments. See **Application Note 84** on our website for details.

We'll talk more about conductivity sensors and dissolved oxygen sensors on the next few slides.

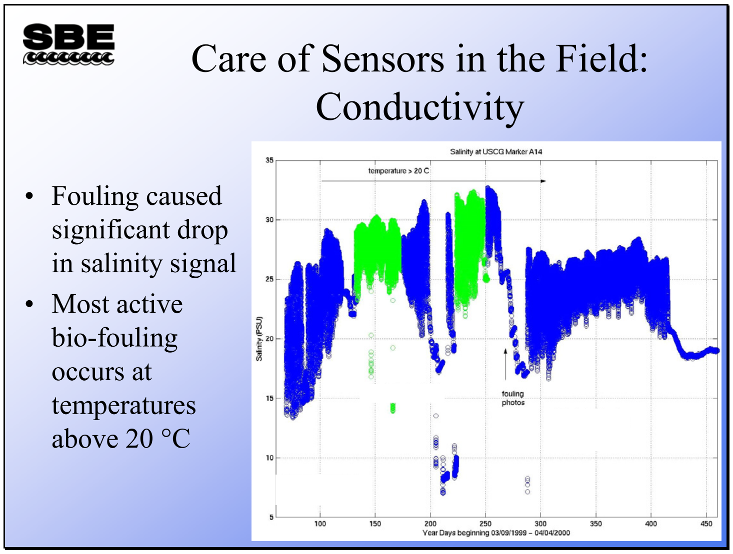
Care of Sensors in the Field: Conductivity



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*)

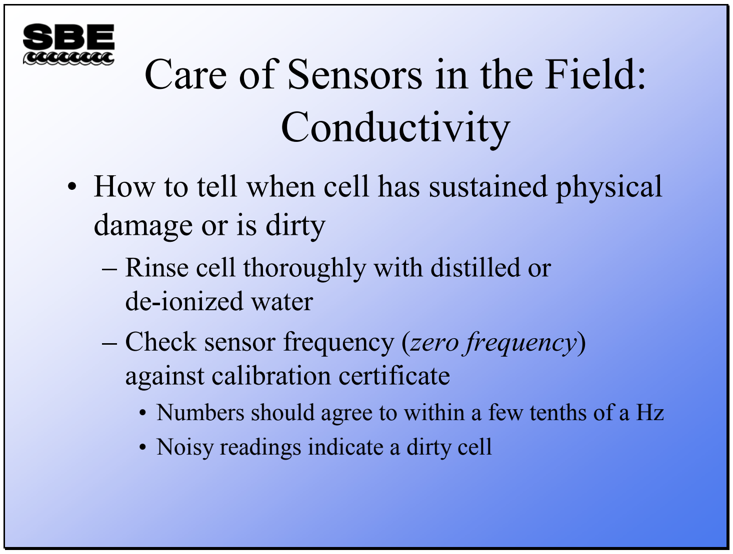
Care of Sensors in the Field: Conductivity (*continued*)



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 another 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 a warm 50:1 chlorine bleach solution followed by a 1 - 2% Triton-X solution is recommended.

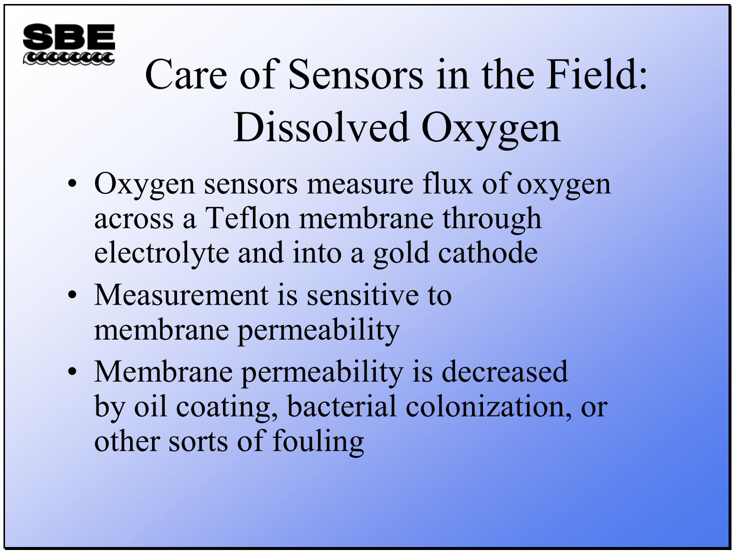
If you suspect that the cell has been overrun by calcareous organisms, then a rinse with an HCl solution will help by removing any calcium carbonate that may have been deposited. Rather than doing this aggressive cleaning yourself, Sea-Bird recommends that the sensor be returned to the factory for cleaning and inspection.

- For the SBE 37-IMP, 37-SMP, and 37-SIP MicroCAT; SBE 49 FastCAT; and any other instruments with an integral, internal pump: **Do not perform acid cleaning**; it must be performed at the factory to avoid damage to the pump.

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.

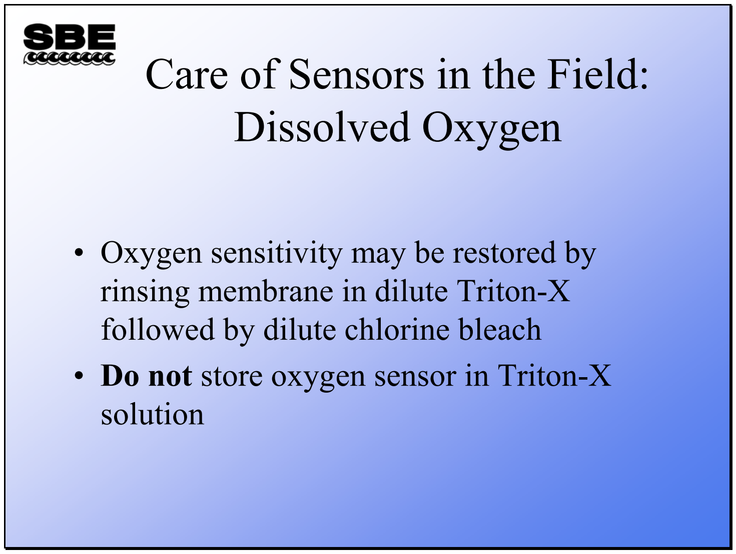
See **Application Note 2D** on our website for details on cleaning conductivity cells.

Care of Sensors in the Field: Dissolved Oxygen



Oxygen sensors become less sensitive when they 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*)



Routine post-cruise cleaning:

1. Rinse your dissolved oxygen sensor with a wash with a 1% Triton-X solution for 1 minute. Drain and flush with warm fresh water for 5 minutes.
2. Follow this with a 1 minute soak with a 50:1 chlorine bleach solution (50 parts de-ionized water to 1 part chlorine bleach). Drain and flush with warm fresh water for 5 minutes.
3. Repeat these steps as necessary.

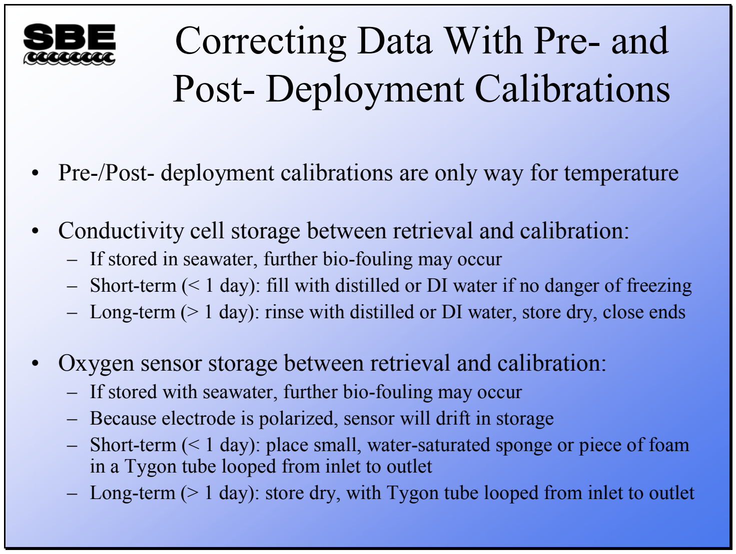
See **Application Note 64** on our website for details on oxygen sensor cleaning and storage.

Correcting Data

Sensor Drift

- Drift same as profiling instruments
- Pressure and temperature drift as offset
  - Typical temperature drift rates for SBE 16*plus*, 16*plus* V2, 37, and 39 are 0.0002 °C per month
  - Typical pressure drifts are linear, with rates of 0.018% - 0.05% of full scale per **year**
- Conductivity and oxygen drift as slope
  - Conductivity drift rates are 0.0003 Siemens/meter/month
  - SBE 43 drift rate is 1 – 2% per month

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.

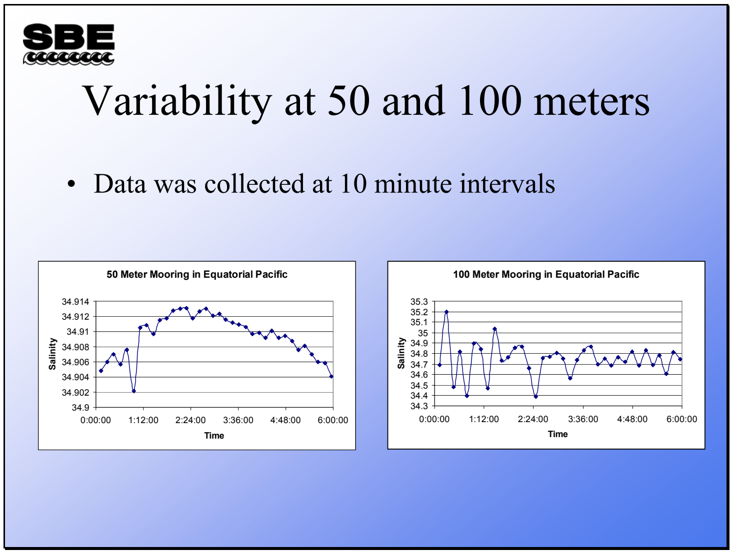
See **Application Note 2D** for details.

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.

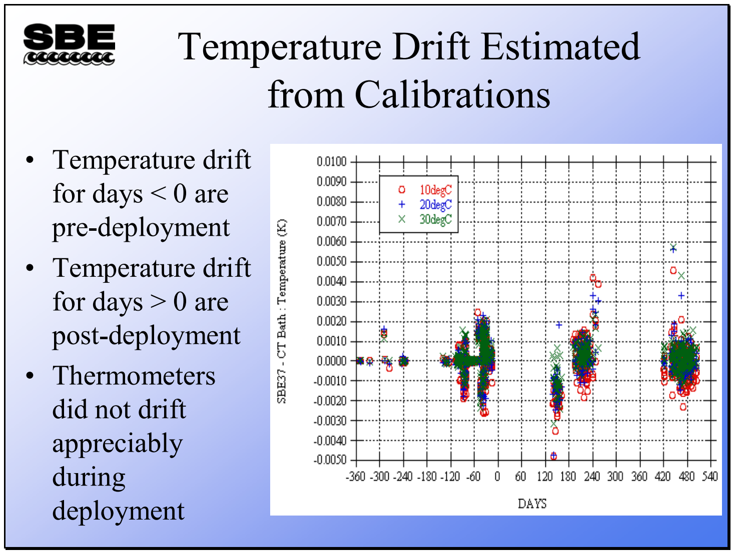
See **Application Note 64** for details.

Correcting Conductivity and Temperature Data: Example



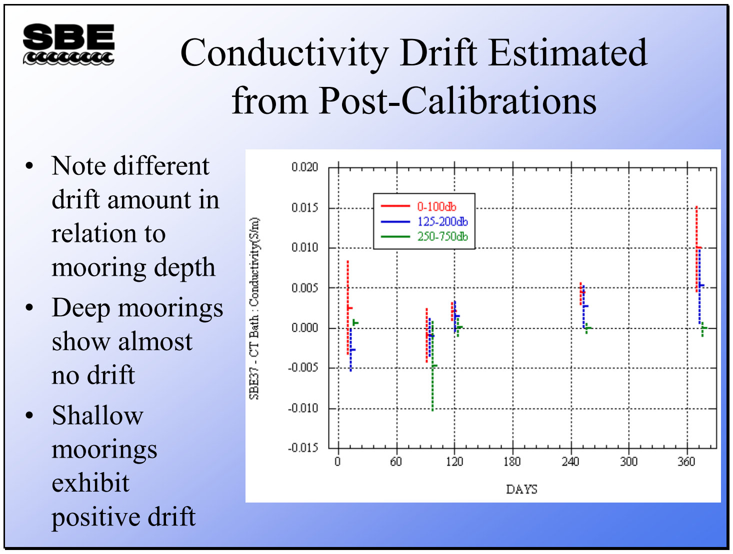
We are going to be comparing data collected by moored instruments with data collected in a CTD profile. It is important to keep in mind that even though the mooring is fixed in place, the ocean moves around it. There can be substantial variability over a fairly small time interval. Most of the time there 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, nearly identical to Sea-Bird's 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*)

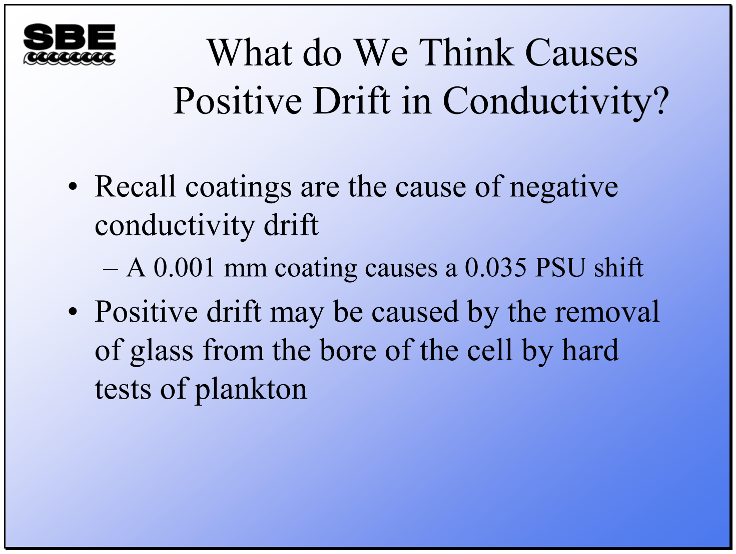


In this plot the drift is estimated at a conductivity value of 6 S/m, and instruments are lumped by mooring depth. Instruments moored in deep water show almost no drift. Those within the surface layer show a positive drift that increases with time. Drift in conductivity sensors is caused by a change 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.

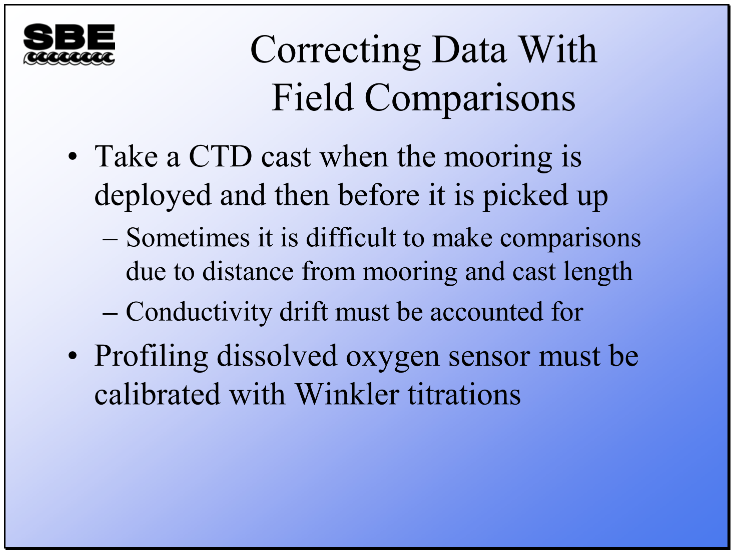
Conductivity: Positive Drift (*continued*)



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.

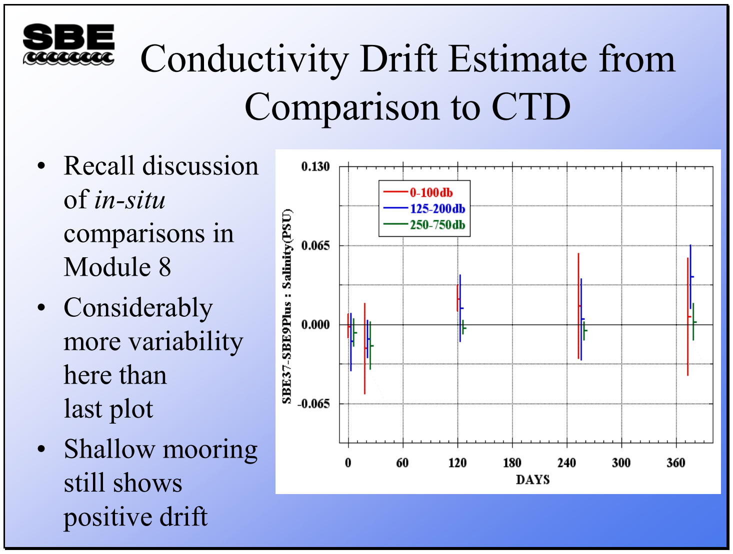
You might think that we could measure the volume of the cell and observe the change in volume. The diameter increase that would produce the errors we are seeing are in the micron range. This change in volume could not be measured gravimetrically. Further, the cross-section of the original cell is not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

Correcting Data



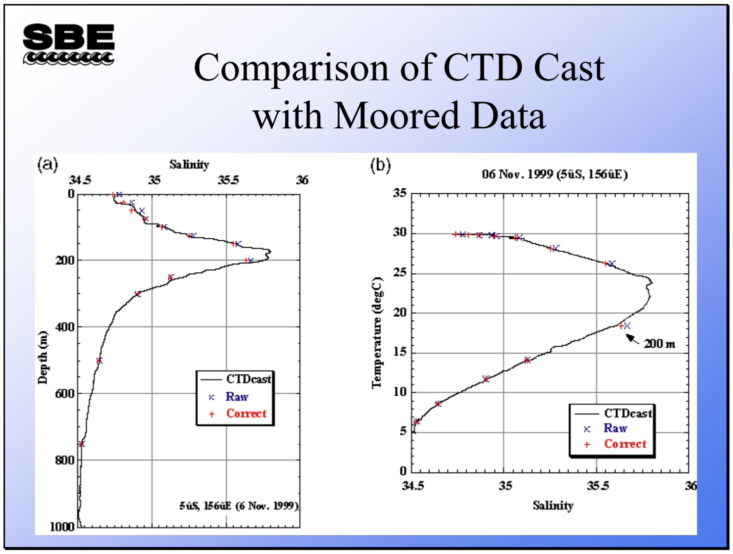
Sea-Bird does not supply software to correct time series data. These corrections are similar to those done on a cast basis for profiled data. An incremental offset is applied to temperature data, assuming the offset drift is linear and monotonic throughout the deployment. For conductivity, an incremental 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 15, 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)

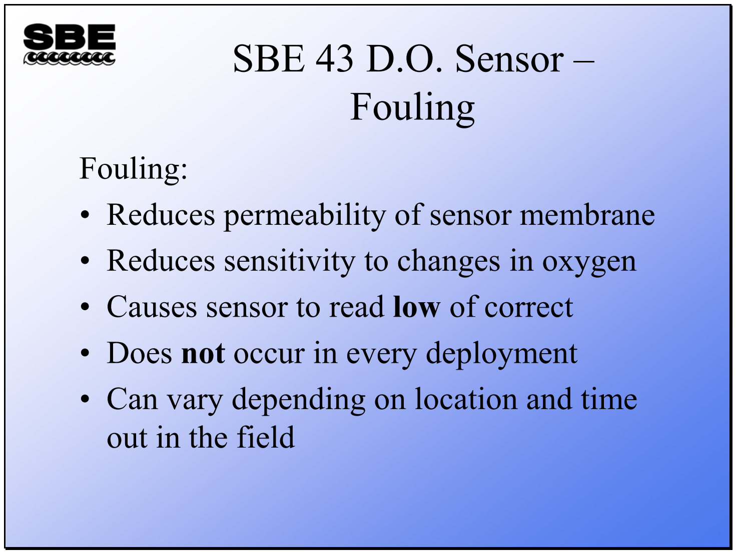
	Raw	Corrected by Calibration
Mean	0.0152	-0.0148
Median	0.0168	-0.0069
Standard Deviation	0.0397	0.0422

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.

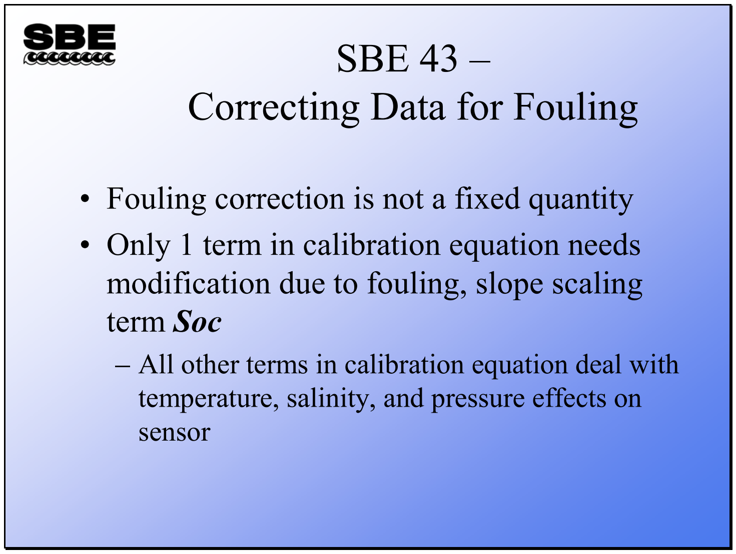
Plots and statistics taken from:

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

SBE 43 Dissolved Oxygen



Correcting SBE 43 Dissolved Oxygen Data



Correcting SBE 43 Dissolved Oxygen Data

SBE 43 –
Correcting Data for Fouling

- Because sensor calibration changes only in slope, you **only need 1 sample to validate**
- Compute correction only if necessary
- Apply correction in configuration (.con or .xmlcon) file prior to processing data with SBE Data Processing

Correcting SBE 43 Dissolved Oxygen Data

SBE 43 – Procedure Overview for Correcting Data for Fouling

- Compare a Winkler value and corresponding SBE 43 value
- Compute correction ratio = (Winkler value / SBE 43 Value)
- Multiply factory ***Soc*** by ratio to get ***newSoc***
- Replace factory ***Soc*** in .con or .xmlcon file with ***newSoc***
- Process data from time of correction forward with ***newSoc***

The correction ratio is typically greater than 1.0 if the sensor is fouling.

Other options for data correction are discussed in several papers on our website.

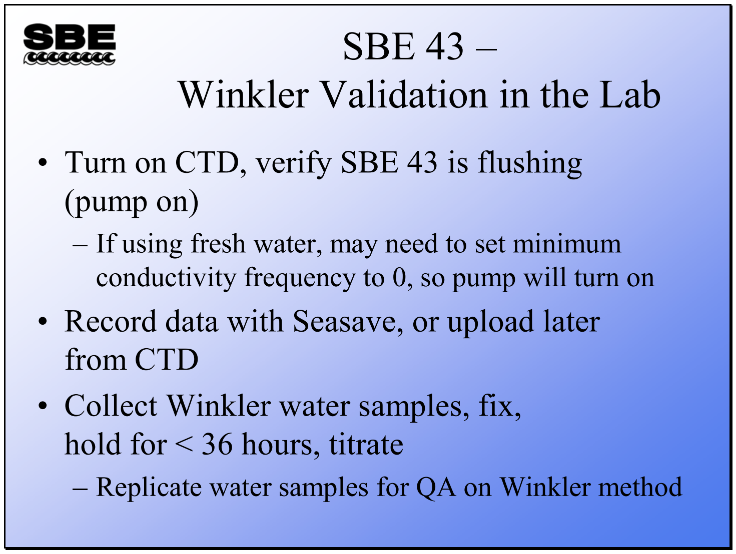
Correcting SBE 43 D.O. Data: Lab Validation

SBE 43 – Winkler Validation in the Lab

- Clean, stirred, temperature-stable bath
  - Fresh water, artificial salt water, or natural salt water
- Aerators are fine, but turn off prior to sampling
- Place CTD with SBE 43 in bath, allow to equilibrate for several hours
  - Equilibrated when temperature signal from CTD is not changing rapidly with time
  - Use Seasave to view real-time data

Correcting SBE 43 D.O. Data: Lab Validation

Correcting SBE 43 D.O. Data: Lab Validation



Note for SBE 9*plus* CTD -

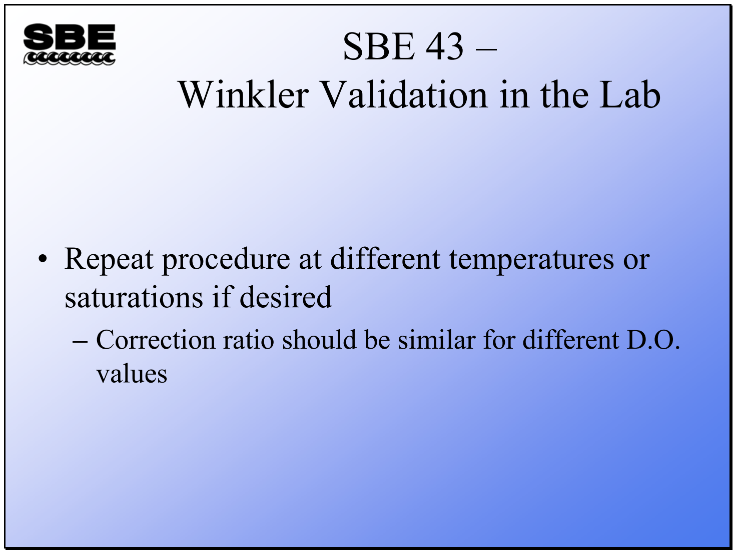
Minimum conductivity frequency cannot be set by the user for an SBE 9*plus* CTD. It is factory set (hard wired) to approximately 3500 Hz. An SBE 9*plus* with custom modifications allows you to manually turn the pump on and off, which can be useful for fresh water applications (or for testing in the lab).

Correcting SBE 43 D.O. Data: Lab Validation

SBE 43 – Winkler Validation in the Lab

- Output time series of CTD data: temperature, conductivity, salinity, oxygen voltage, OxSat, oxygen concentration (same units as Winkler values you are generating)
- Pull data from CTD time series that corresponds with time of Winkler samples
  - Enter CTD data and Winkler data in a spread sheet
  - Compute correction ratio

Correcting SBE 43 D.O. Data: Lab Validation



Correcting SBE 43 D.O. Data: Field Validation

SBE

SBE 43 – Winkler Validation in the Field

- Follow similar procedure for validation in field
- Choose depth of CTD and Winkler water sample comparisons where D.O. is not changing much
  - Collect replicate field samples if possible, and use average or "best of"
- If replication not possible, collect samples at multiple locations to get idea of sampling variability and to be sure you do not have a bad sample

Field validations must be carefully executed!

For additional information on SBE 43 data and corrections, see **Application Notes 64, 64-1, and 64-2** on our website.

Activity: Compute Correction Factor for *Soc*

Activity:
Compute Correction Factor for *Soc*

Winkler (ml/l)	SBE 43 (ml/l)	Difference (SBE 43 – Winkler)	Correction Factor (Winkler/SBE 43)
6.8	5.8		
4.2	3.6		
1.2	1.0		

- If factory ***Soc*** was 0.4109, calculate ***newSoc***

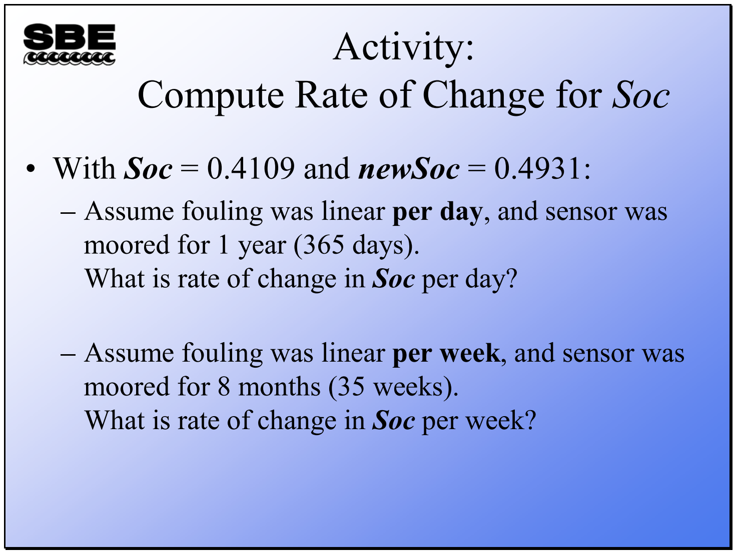
The new ***Soc*** (***newSoc***) is entered in the configuration (.con or .xmlcon) file in SBE Data Processing. The modified configuration file is used for processing measurements made after the date corresponding to the Winkler water samples.

Computing Rate of Change for *Soc*

Computing Rate of Change for *Soc*

- Correction factor you just computed should yield ***newSoc*** = 0.4931 (using correction factor of 1.2)
- You could also apply a constant slope correction per day (or week or month) by computing a rate of change in ***Soc*** and processing data accordingly
- For example, let's assume fouling over mooring period was linear per day. Computing daily rate of change assuming sensor was moored for 244 days:
  Rate of change = (***NewSoc* – *Soc***) / # of days
  = (0.4931 – 0.4109) / 244 = 0.0003368/day

Activity: Compute Rate of Change for *Soc*



Correcting Oxygen Data: Example

SBE

Example: Shilshole Marina

Date (2007)	Winkler 1	Winkler 2	Winkler 3	Average	Standard Dev
3/12	(Calibration date)				
3/23 17:10	6.123	6.165	6.239	**6.176**	**0.059**
3/30 11:10	7.077	7.084	7.111	**7.091**	**0.018**
4/19 12:20	7.324	7.328	Dud	**7.326**	**0.003**
5/04 13:10	7.552	7.579	7.569	**7.567**	**0.014**
5/04 14:10	7.643	7.742	7.765	**7.717**	**0.065**
5/17 13:10	8.239	8.250	8.248	**8.246**	**0.006**
5/30 12:40	9.025	9.184	9.146	**9.118**	**0.083**
6/05 15:20	8.517	8.509	8.488	**8.505**	**0.015**

Sea-Bird deployed an SBE 43 on a CTD at Shilshole Marina in Seattle from March 23 to June 5, 2007, and performed periodic water sampling at various times during the deployment period. The table above summarizes the Winkler results from the water samples.

Note that 3 water samples were drawn and analyzed from the bottle collected on each water sampling date. We will use the average Winkler value on each date to perform the corrections. The standard deviation in the Winklers gives an estimate on method draw and lab errors. It does not account for co-sampling (location/timing) errors with respect to the oxygen sensor.

Correcting Oxygen Data: Example (*continued)*

SBE

Example: Shilshole Marina

Date (2007)	SBE 43 **	Difference (Winkler – SBE 43)	Ratio (Winkler / SBE 43)	newSoc	Corrected SBE 43
3/12	Calibration Date, ***Soc*** = 0.00012913				
3/23 17:10	6.028	0.148	1.024	0.00013223	**6.176**
3/30 11:10	6.789	0.302	1.044	0.00013481	**7.091**
4/19 12:20	6.885	0.441	1.064	0.00013739	**7.326**
5/04 13:10	7.236	0.331	1.045	0.00013494	**7.567**
5/04 14:10	7.319	0.398	1.054	0.00013610	**7.717**
5/17 13:10	7.740	0.506	1.065	0.00013752	**8.246**
5/30 12:40	8.470	0.648	1.077	0.00013907	**9.118**
6/05 15:20	7.789	0.716	1.092	0.00014101	**8.505**

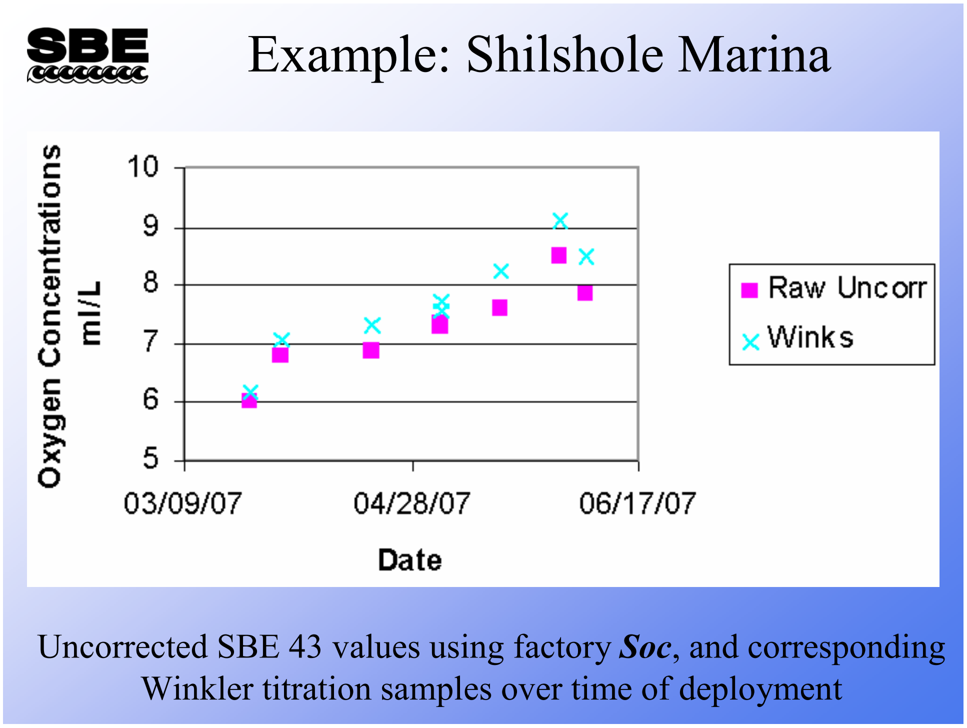
** Using original ***Soc*** (= 0.00012913)

Looking at these data, the percent change in ***Soc*** from beginning of deployment to end of deployment (3/23 to 6/5, approximately 2.5 months) is 7%.

Note the following:

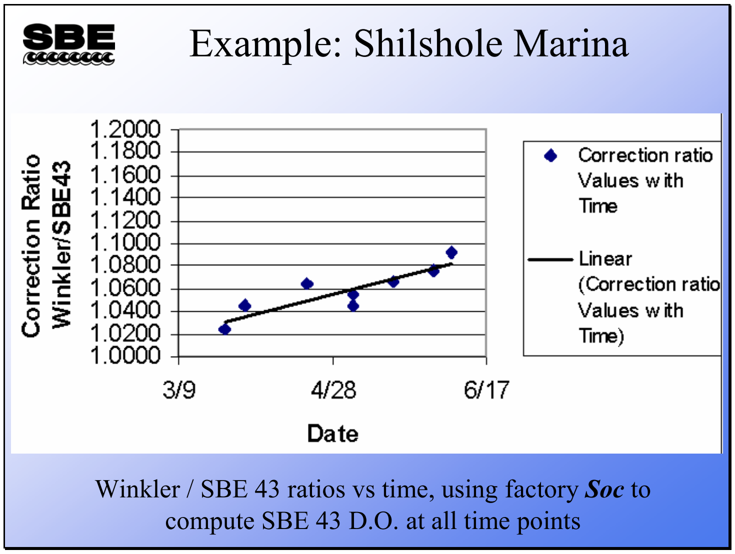
- The corrections would be small (< 4%) through 5/17.
- Have an idea what level of data accuracy you expect.
- Look for outliers - they could indicate a problem in your calculations, or that the sensor and water samples do not agree (for example, co-sampling errors and time of sample with sensor mismatches).
- There are many ways to implement corrections. For examples, see our website.
- Tracking data can help identify instrument or coefficient problems.
- It is not normal for the ratios and resulting ***Soc*** values to decrease with time.
  1) Verify calibration coefficients are entered in the configuration (.con) file correctly.
  2) Contact customer service with a sample of the problem you are seeing.
  3) Return the SBE 43 to the factory for assessment if the problem is not resolved.
- Sea-Bird recommends factory servicing when the ***Soc*** correction ratio factor ~ 1.2 (equivalent to 15 - 20% drift from factory calibration), **and** it is not corrected by sensor cleaning.

Correcting Oxygen Data: Example (*continued)*



Uncorrected SBE 43 values using factory ***Soc***, and corresponding Winkler titration samples over time of deployment

Correcting Oxygen Data: Example (*continued)*



This plot shows the Winkler / SBE 43 ratios versus time, using the original factory calibration value to compute the SBE 43 D.O. at all time points.

Notice the small positive trend in the correction with time. Sea-Bird recommends a factory service when the correction ratio reaches 1.2 and is not corrected with cleaning.