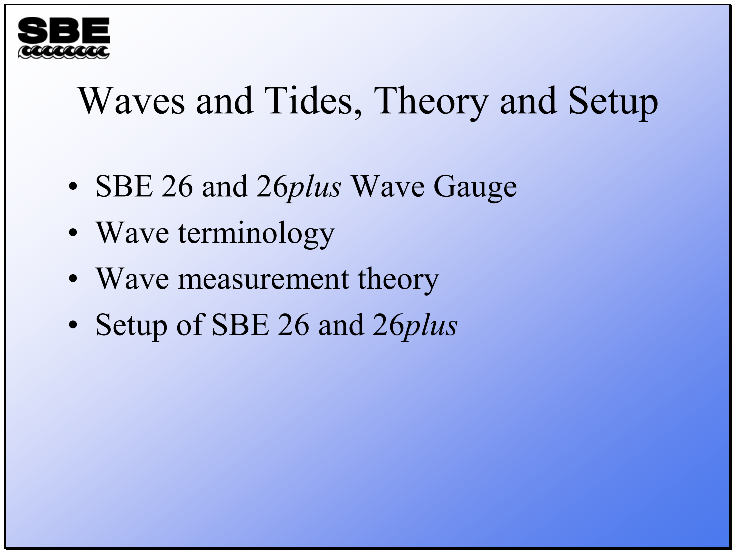
Module 13

Wave and Tide Instruments: Theory and Setup

Overview

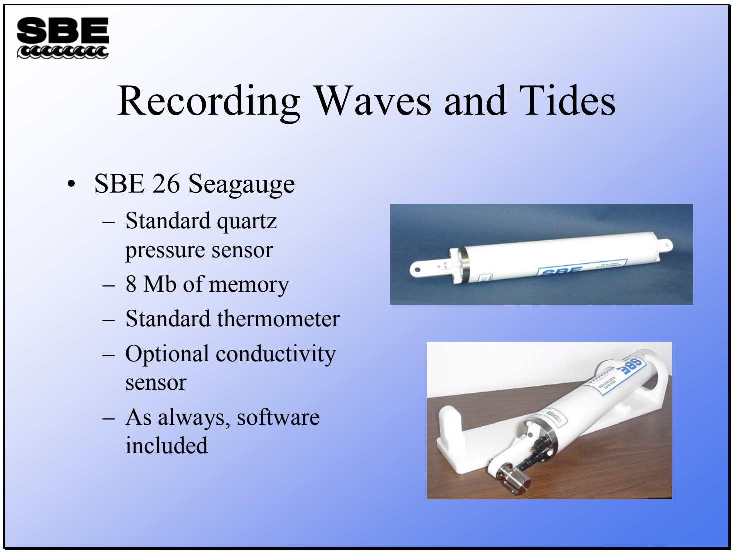


In this module we will be discussing Sea-Bird's SBE 26 and 26*plus* wave and tide recorder. We will spend some time on wave terminology and measurement theory. This topic tends to get very mathematical quickly, so we will just hit the high points. Finally, we will discuss setting up an SBE 26 and a 26*plus*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

By the end of this module you should be:

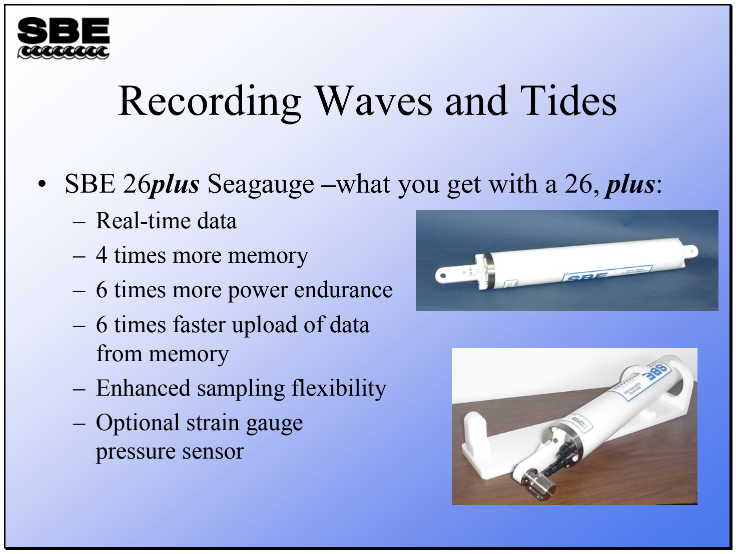
- Able to describe what sort of waves we are measuring.
- Aware of the limitations of the measurement technique.
- Able to set up an SBE 26 and 26*plus* for deployment.

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

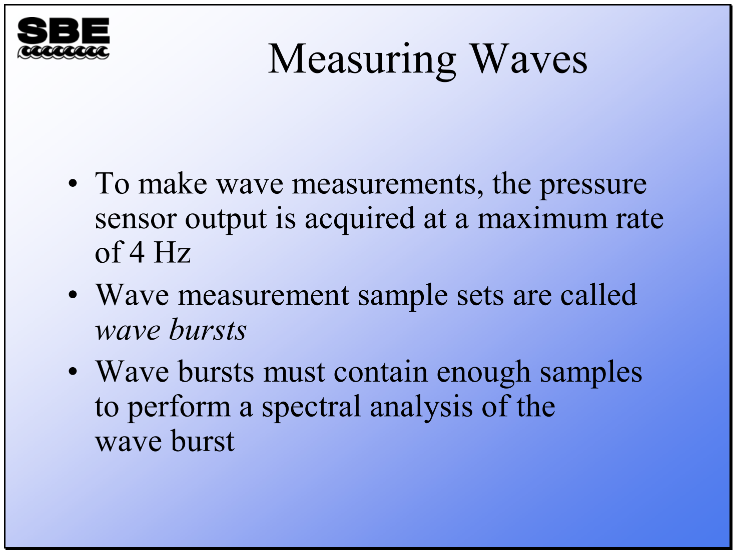
Measuring Tides

Measuring Tides

- Quartz pressure sensor has frequency output.
- SBE 26 goes to sleep, but pressure frequency is counted continuously. SBE 26 wakes, reads counters, and resets them.
- SBE 26*plus* can operate like 26, or can conserve battery power by counting pressure frequency for only a portion of tide interval.
- Pressure is determined by knowing the number of counts and the time interval between counter reads.

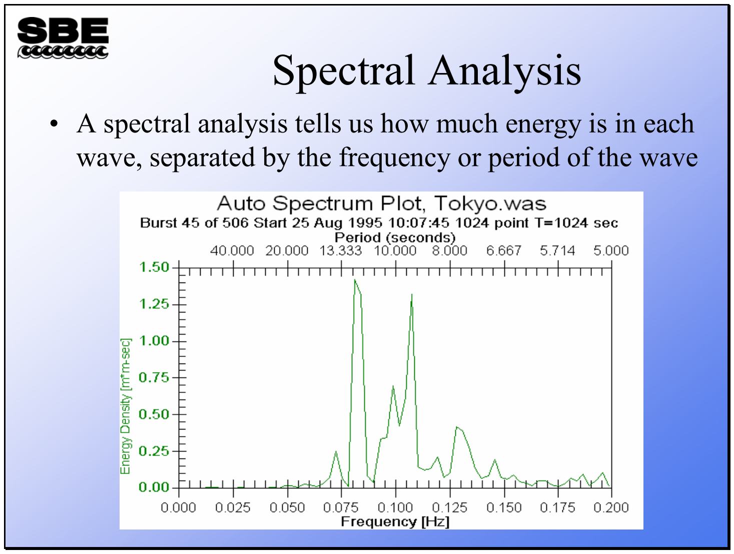
By accumulating pressure sensor frequency counts for the whole sample interval, the SBE 26 / 26*plus* integrates the pressure signal over the entire sampling time. If the sample time is sufficiently long, the influence of surface waves is removed.

Measuring Waves



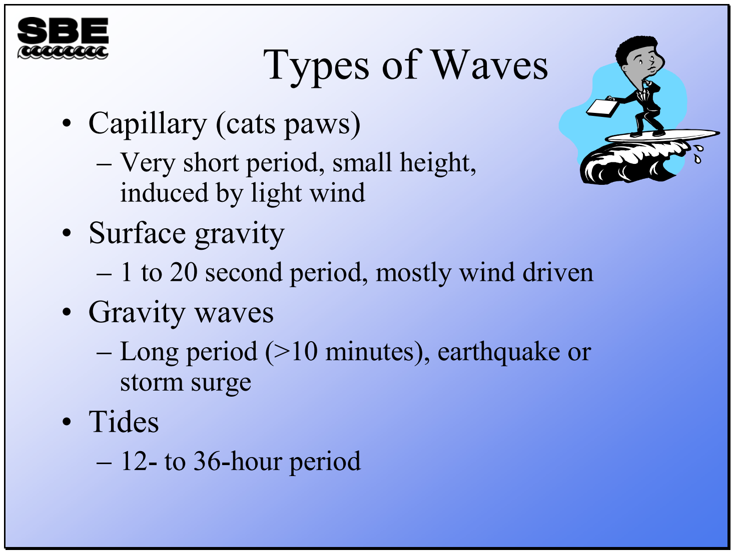
The spectral analysis of wave burst is based on the Fast Fourier Transform. Because of this, the analysis is most accurate if the number of wave burst samples is a power of 2. Further, the more samples in the wave burst, the more accurate the estimation of the wave spectrum. You must balance the desire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

Wave Frequency Spectrum



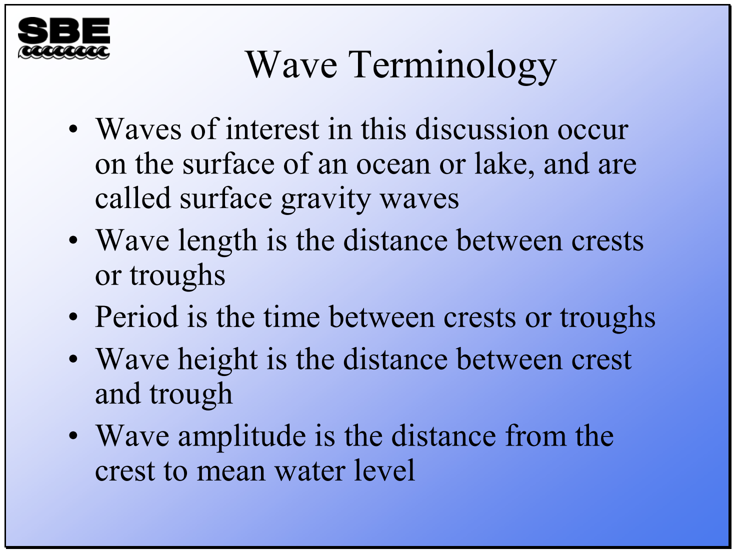
The characteristics of the spectral analysis are determined by the number of data points in the wave burst, the sample rate, and the physical location of the SBE 26 or 26*plus*. The characteristics we are speaking of are the band width or frequency resolution and the maximum frequency of our analysis.

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*)

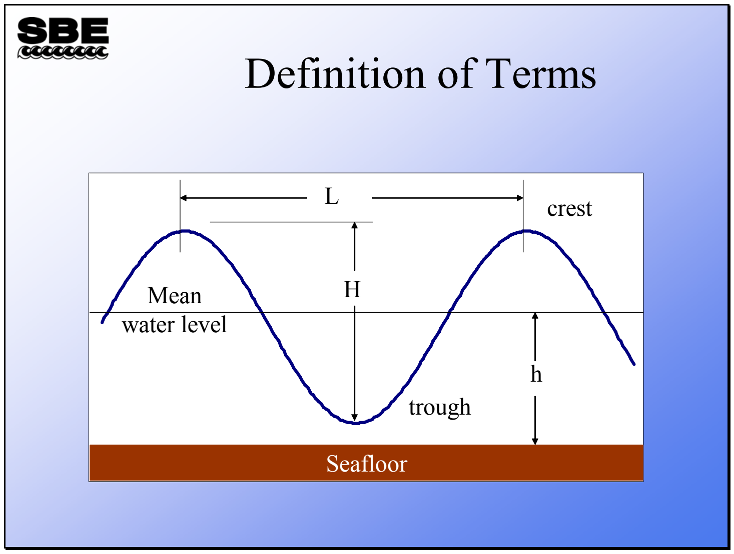


Some of the parameters that we will be able to determine for a wave burst are:

- 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

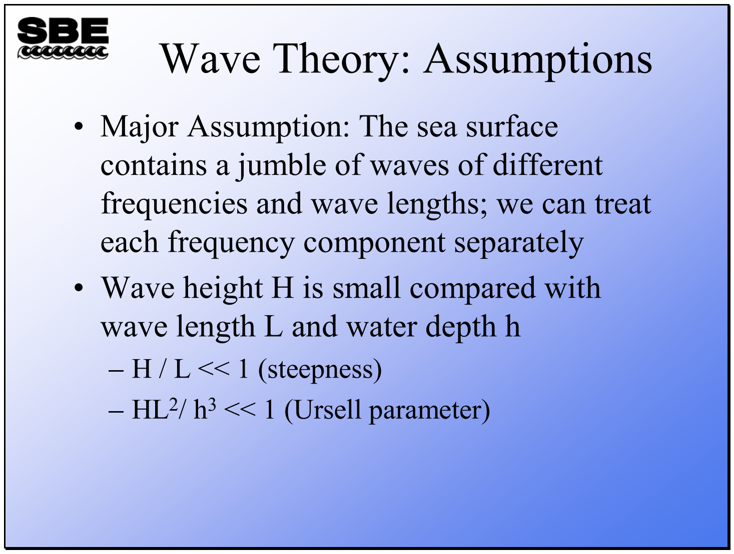
h = water depth in meters

Additional terms:

T = wave period in seconds

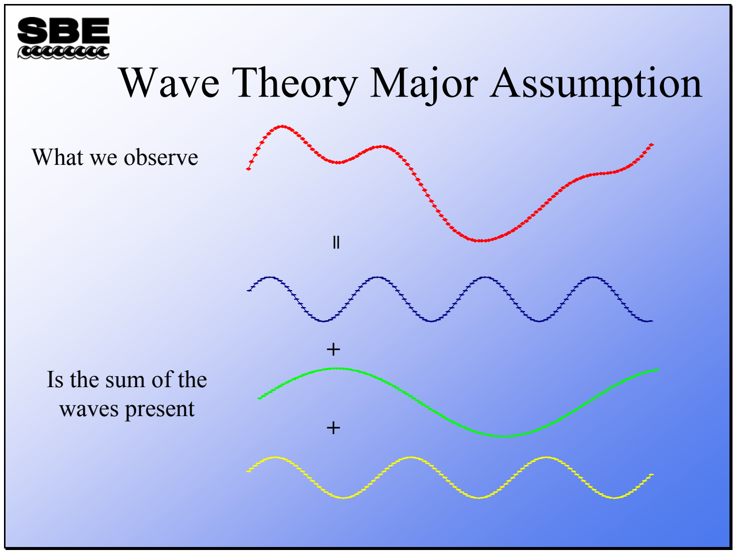
G = 9.80665, acceleration of gravity, m/s^2

Measuring Waves: Background (*continued*)



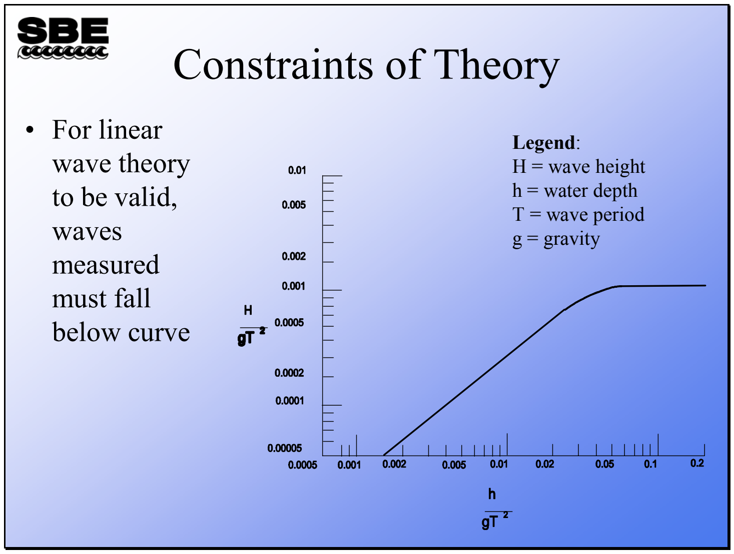
The *major assumption* above is known as linear theory. It supposes that the sea surface we observe is made up of waves of different frequencies, that these waves are superimposed upon one another, and that we can treat each frequency component or wave separately.

Measuring Waves: Background (*continued*)



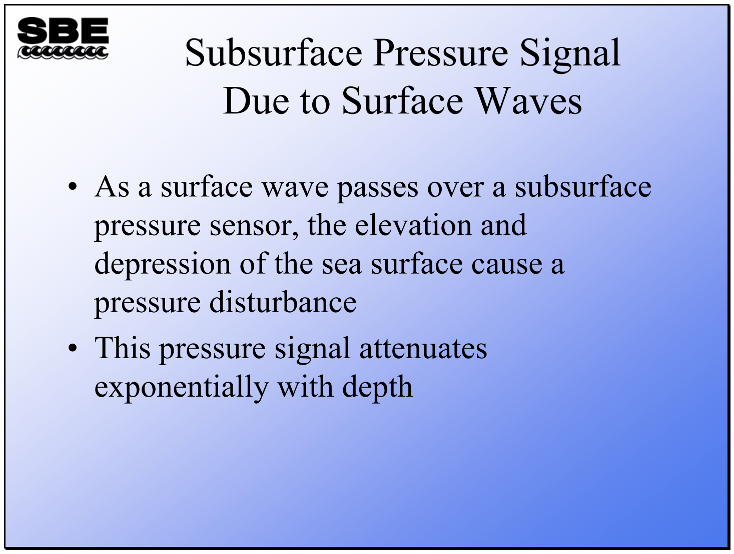
Here is an example of linear theory. The top wave form looks like a sea surface we might observe. It is the sum of the three sinusoids show below it.

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*)

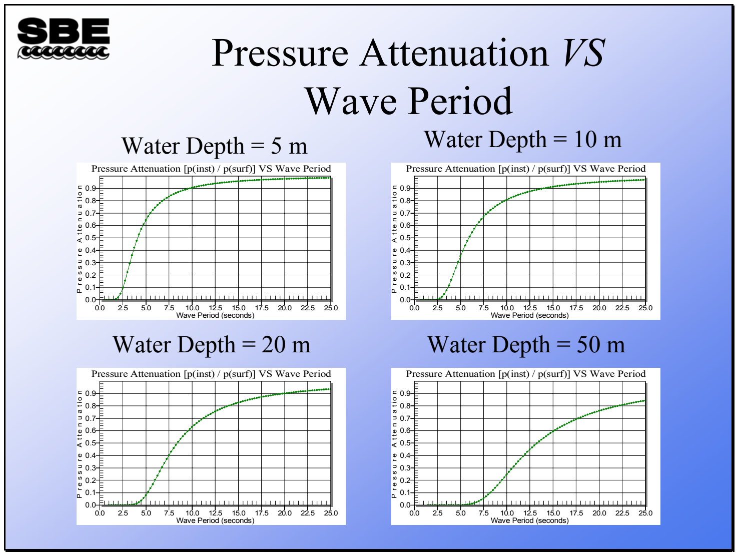
SBE

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	-----	-----

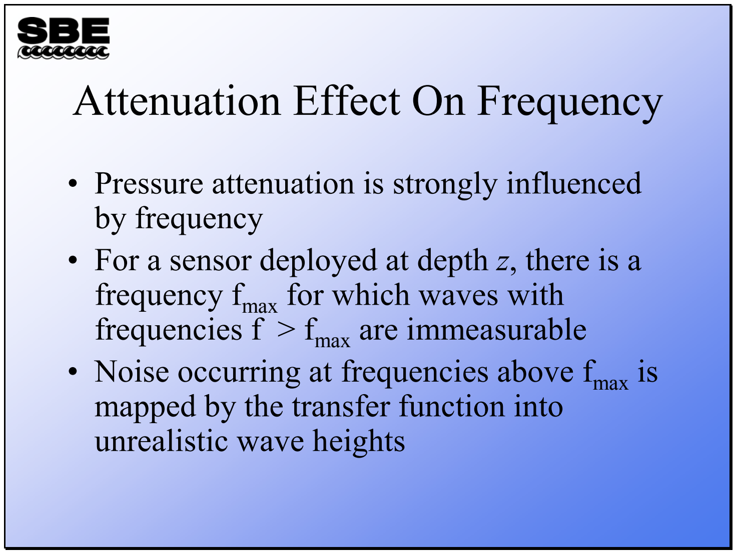
This table was made with the DOS program Wdisp. It shows that the higher the frequency (or the shorter the wave period) that you wish to measure, the closer you have to place your pressure sensor to the surface.

Measuring Waves: Background (*continued*)



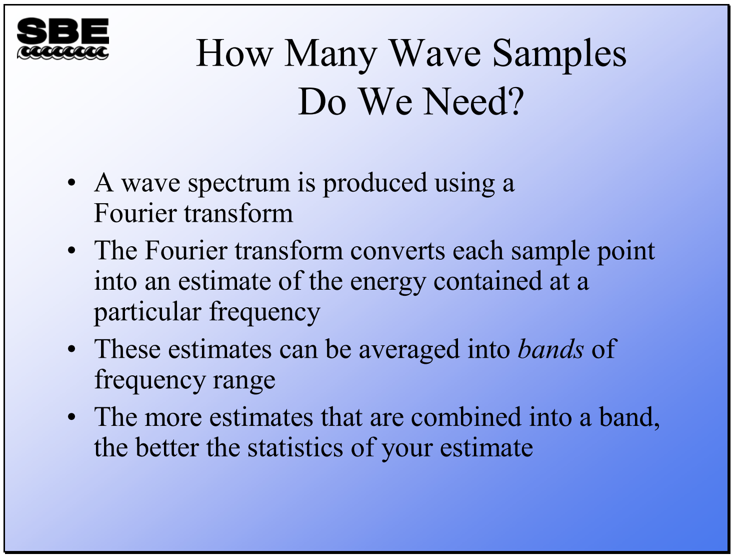
Here are examples of attenuation curves for an SBE 26 or 26*plus* deployed 1 meter off the bottom at 4 different water depths. You can observe that the slope of the curve becomes shallower and that the minimum measurable wave period increases (frequency decreases) as the water depth increases.

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.

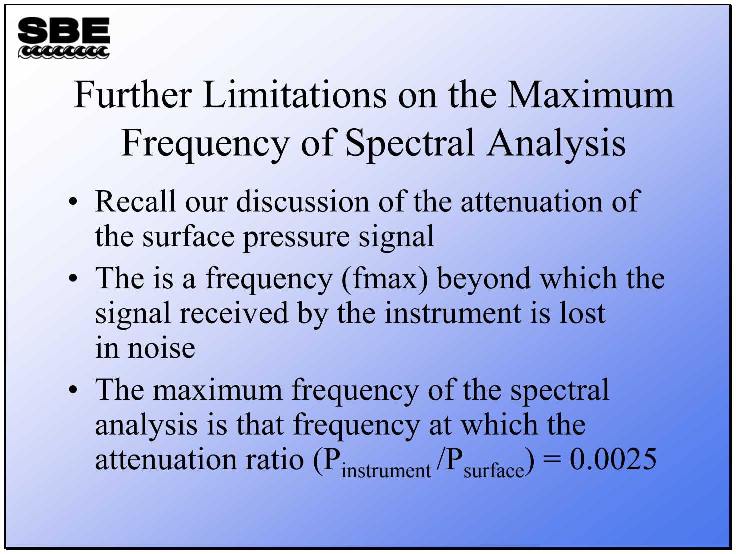
Measuring Waves: Background (*continued*)



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.

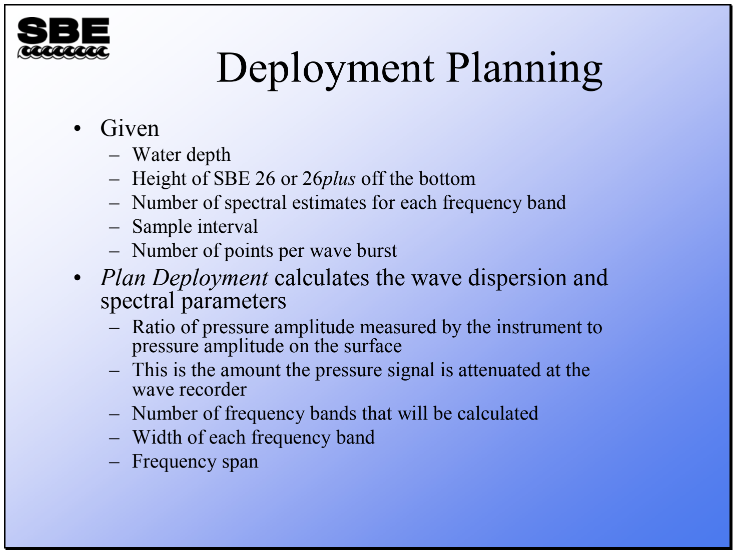
If you lump some of the energy estimates into bands, the average of these estimates provides a more statistically meaningful value.

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



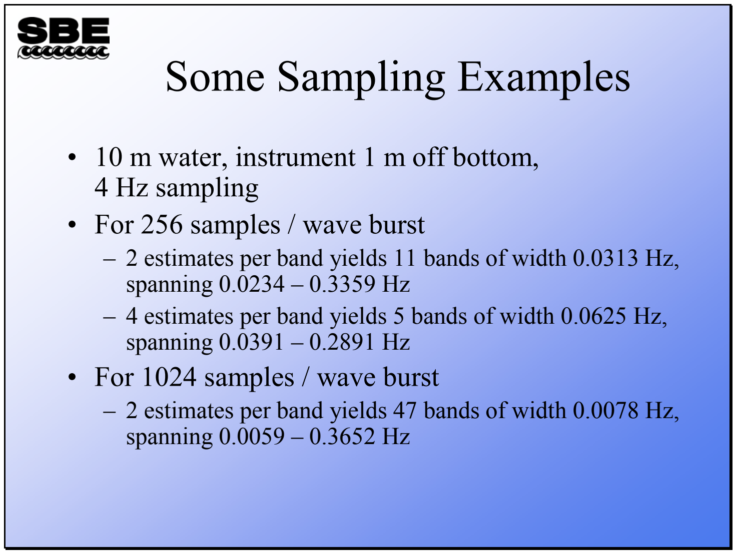
This is the first step. *Plan Deployment* tells you the minimum wave period you can detect given the water depth and the height of the SBE 26 or 26*plus* off the bottom. If you know what period of waves you are interested in, you can adjust your instrument placement to successfully measure these. Conversely, 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.

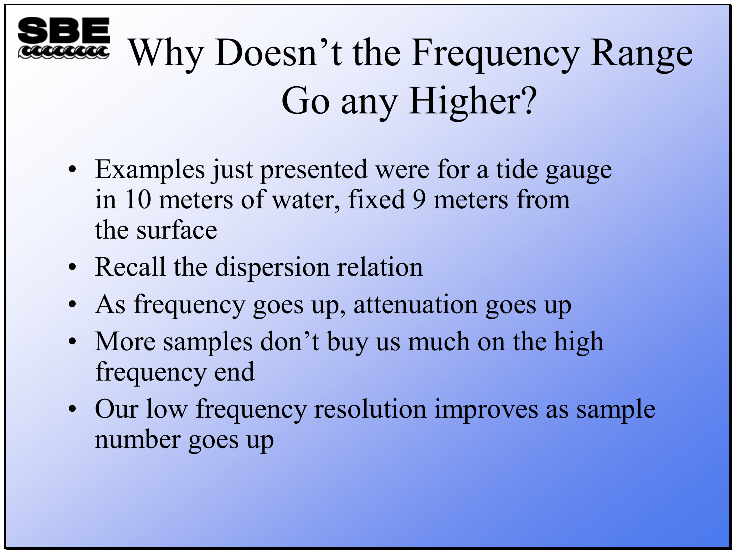
Deployment Planning (*continued*)

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*)

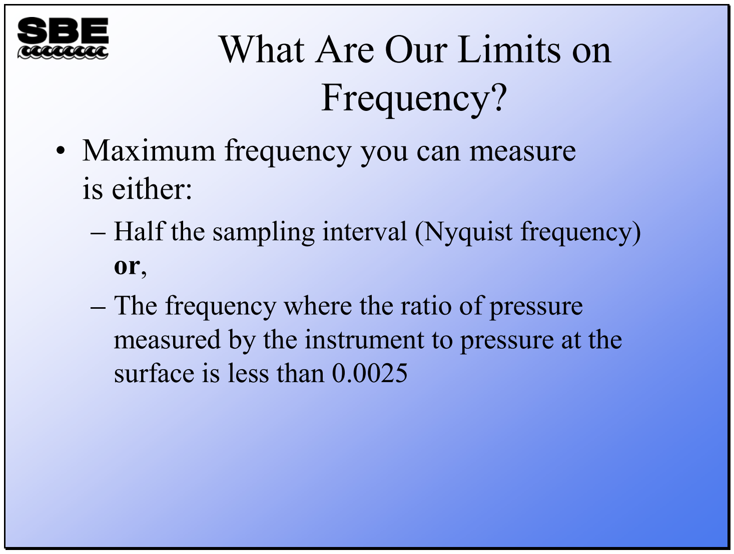


Deployment Planning (*continued*)

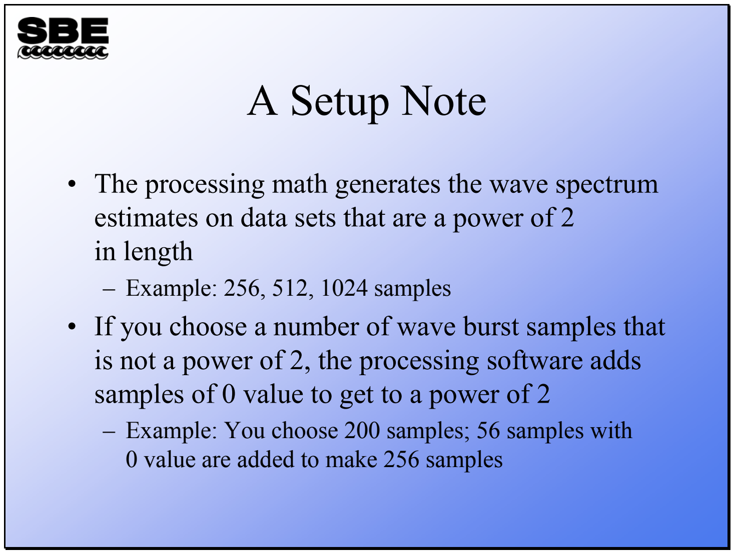


In summary, more samples equals better resolution and better statistics. Your maximum frequency is determined solely by the distance from the sea surface to your instrument and its height off the bottom.

Deployment Planning (*continued*)

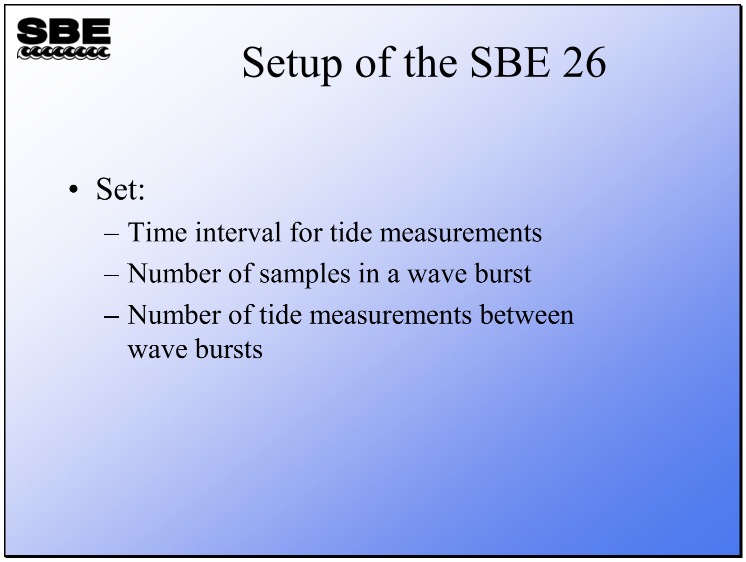


Deployment Planning (*continued*)

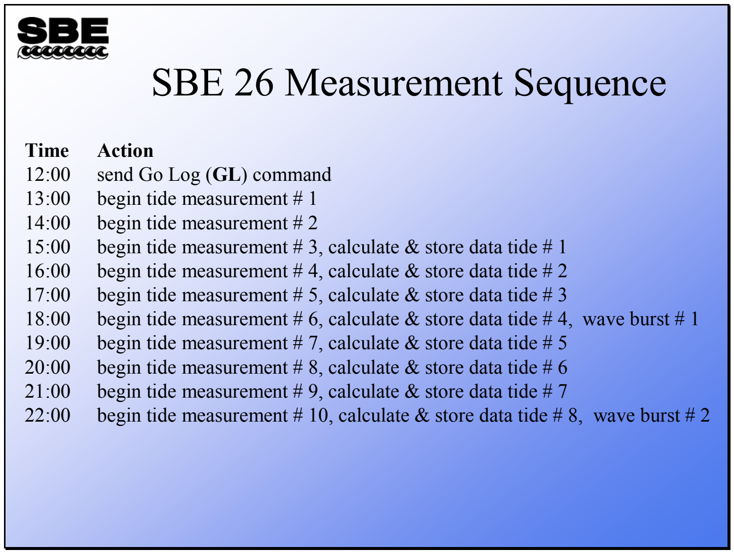


Fast Fourier Transforms are done on data sets that have 2^N elements. If you select a wave burst sample number that is not a power of 2, your data set will be extended to a power of 2 and padded with zeros. While you may save memory this way, you will lose resolution and degrade the statistical confidence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

Setting up the SBE 26

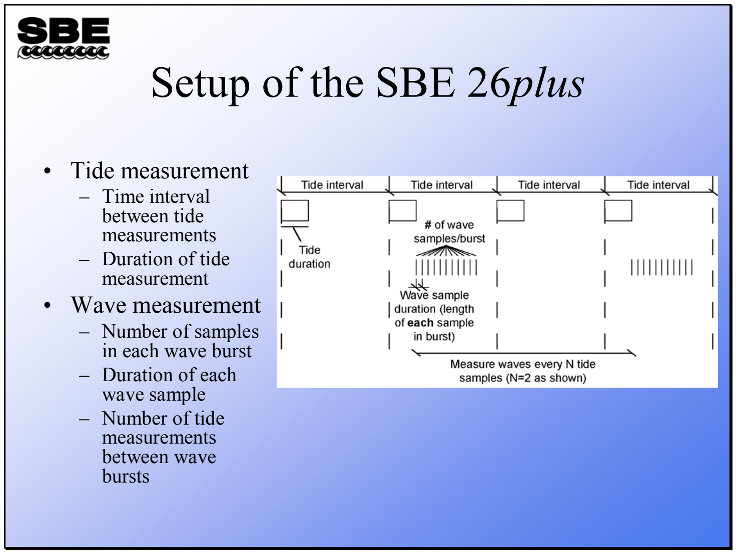


SBE 26 Measurement Sequence



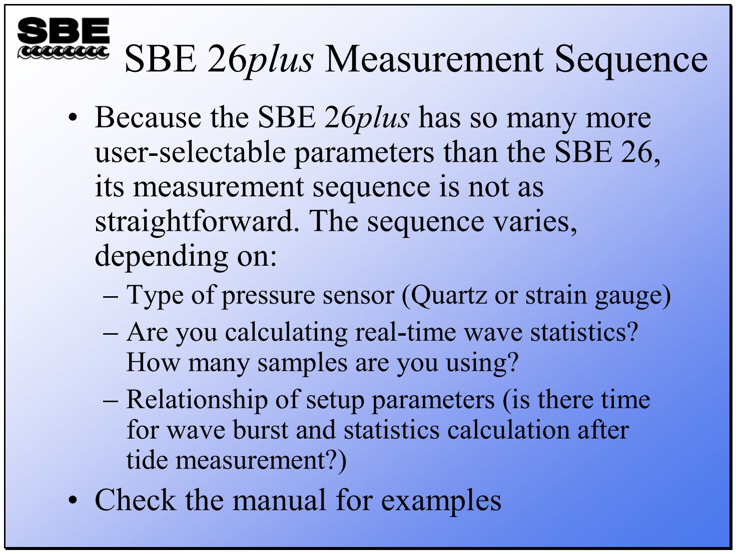
Here is an example measurement sequence for an SBE 26. Tide measurements are an hour in length and a wave burst is done every 4 tide measurements. Because of the frequency counter hardware, a pair of tide measurements is required to calculate the pressure sensed by the SBE 26. Wave bursts are measured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

Setting up the SBE 26*plus*

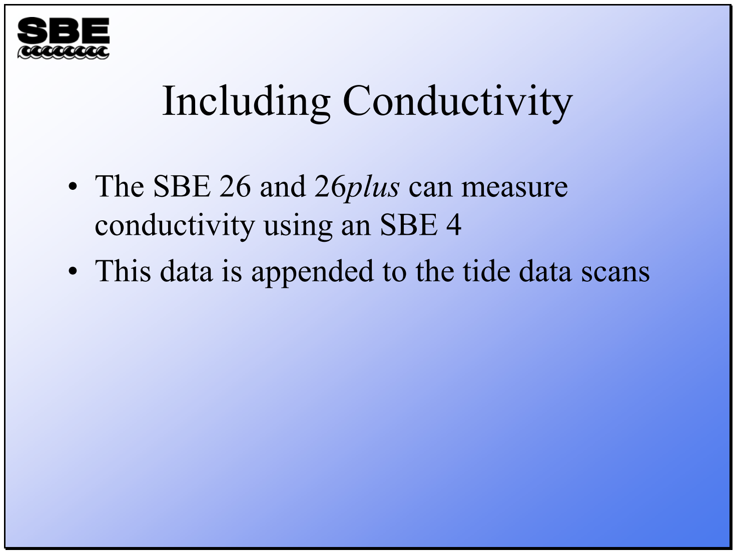


This is just a schematic to illustrate the setup parameters for the SBE 26*plus*. The actual sequencing of the measurements varies, depending on the relationships between the setup parameters.

SBE 26*plus* Measurement Sequence



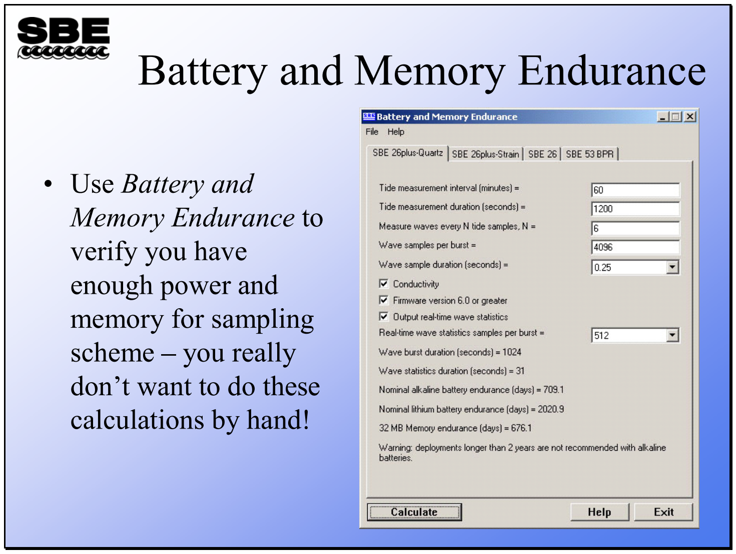
Adding Conductivity



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

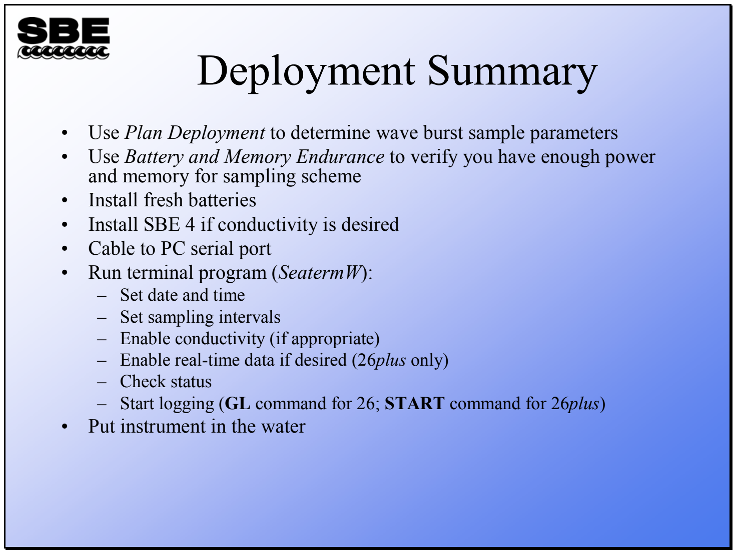
- Connect the conductivity sensor to the instrument's 3-pin bulkhead connector
- Program the instrument to append the conductivity data to the data stream, using the **CY** command in the SBE 26 or the **CONDUCTIVITY=Y** command in the SBE 26*plus*.

Battery and Memory Endurance

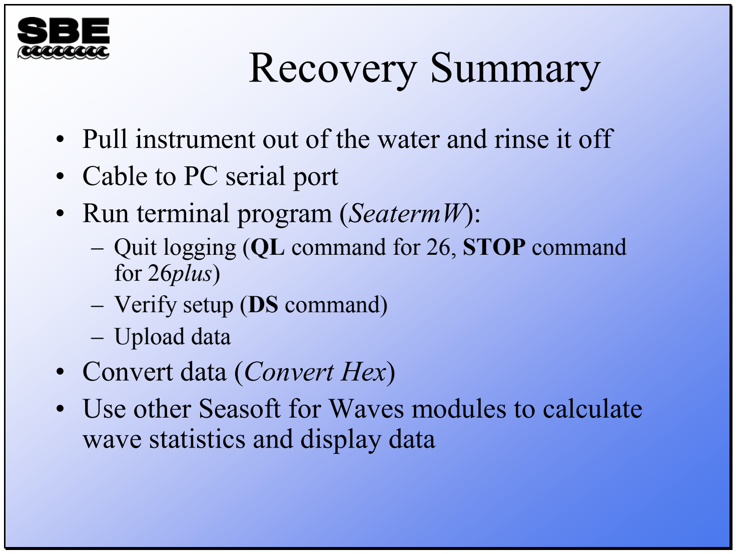


There are separate calculations for the SBE 26 and 26*plus*, and as you can see the 26*plus* is further broken down, depending on the type of pressure sensor. If you are not sure what type of pressure sensor is in your 26*plus*, send the status (**DS**) command in SeatermW; the third line of the response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

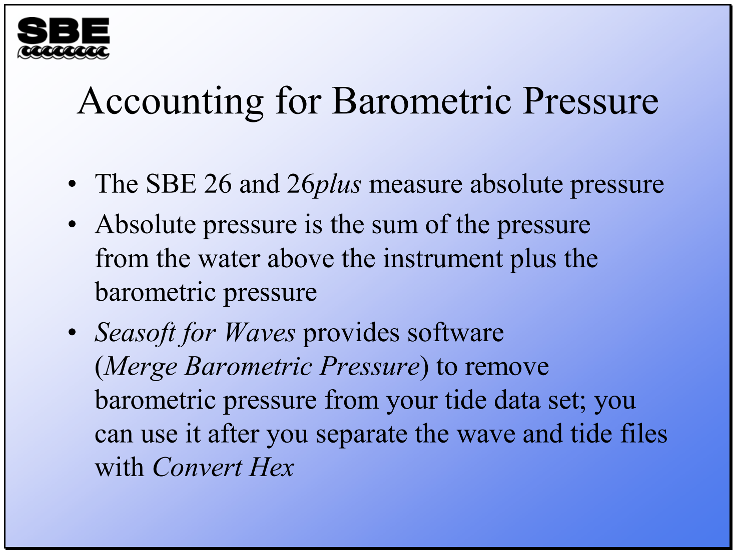
Deployment Summary



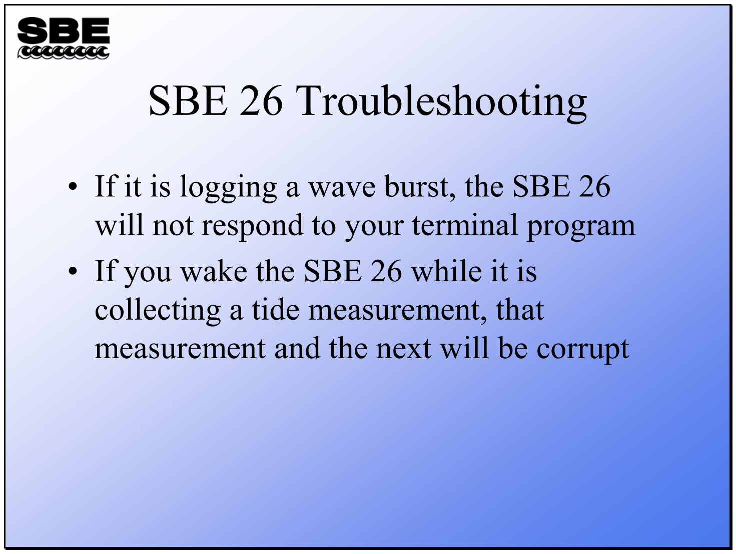
Recovery Summary



Removing Barometric Pressure from Tide Data



Troubleshooting an SBE 26



Troubleshooting an SBE 26*plus*