

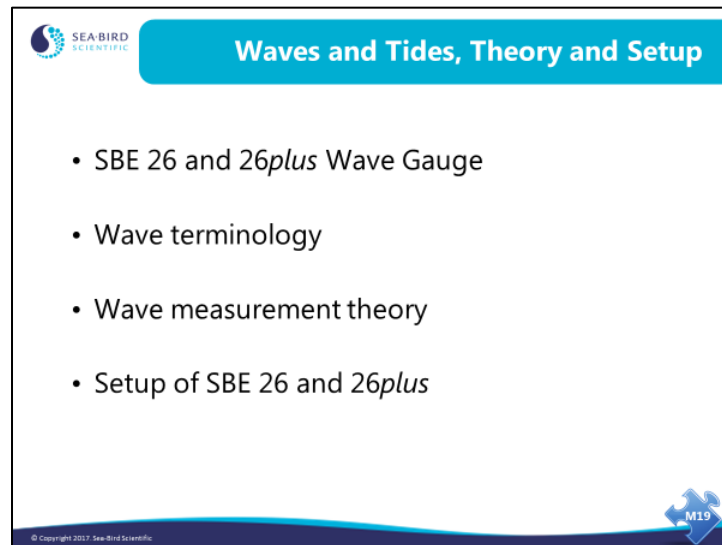


Wave and Tides, Theory and Setup

Sea-Bird Scientific University Module 19



Overview



The slide features the SEA-BIRD SCIENTIFIC logo in the top left corner. The title 'Waves and Tides, Theory and Setup' is displayed in a blue header bar. The main content is a bulleted list of four items. In the bottom right corner, there is a blue icon with the text 'M19' and a copyright notice '© Copyright 2017, Sea-Bird Scientific' in the bottom left corner.

- SBE 26 and *26plus* Wave Gauge
- Wave terminology
- Wave measurement theory
- Setup of SBE 26 and *26plus*

In this module we will be discussing Sea-Bird's SBE 26 and *26plus* 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 *26plus* 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 *26plus* for deployment.

SBE 26 Wave and Tide Recorder

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Recording Waves and Tides

- SBE 26 Seagauge
 - Standard quartz pressure sensor
 - 8 Mb of memory
 - Standard thermometer
 - Optional conductivity sensor
 - As always, software included



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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 *9plus*, 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

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Recording Waves and Tides


- SBE 26*plus* Seagauge – what you get with a 26, **plus:**
 - Real-time data
 - 4 times more memory
 - 6 times more power endurance
 - 6 times faster upload of data from memory
 - Enhanced sampling flexibility
 - Optional strain gauge pressure sensor

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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

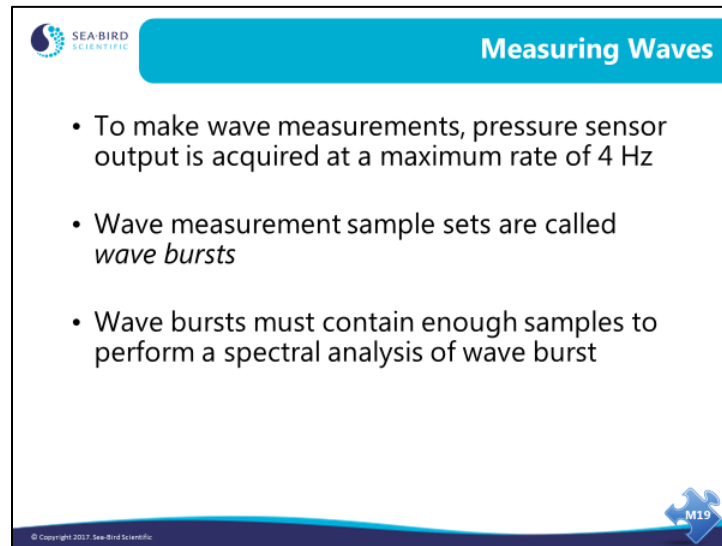
- Quartz pressure sensor has frequency output
- SBE 26 goes to sleep, but pressure frequency is counted continuously; SBE 26 wakes, reads counters, and resets them
- SBE 26*plus* can operate like 26, or can conserve battery power by counting pressure frequency for only a portion of tide interval
- Pressure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

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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



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Measuring Waves

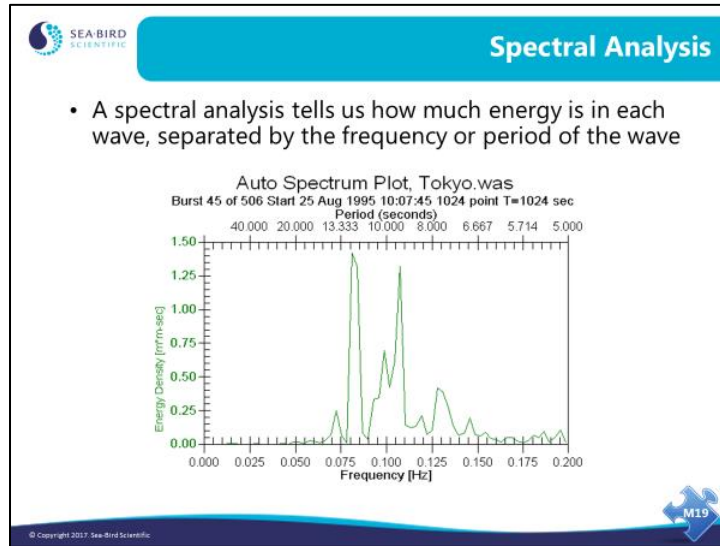
- To make wave measurements, pressure sensor output is acquired at a maximum rate of 4 Hz
- Wave measurement sample sets are called *wave bursts*
- Wave bursts must contain enough samples to perform a spectral analysis of wave burst

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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

SEA-BIRD SCIENTIFIC **Types of Waves**


- Capillary (cats paws)
 - Very short period, small height, induced by light wind
- Surface gravity
 - 1 to 20 second period, mostly wind driven
- Gravity waves
 - Long period (>10 minutes), earthquake or storm surge
- Tides
 - 12- to 36-hour period

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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*)



Wave Terminology

- Waves of interest in this discussion occur on the surface of an ocean or lake, and are called surface gravity waves
- Wave length is distance between crests or troughs
- Period is time between crests or troughs
- Wave height is distance between crest and trough
- Wave amplitude is distance from crest to mean water level

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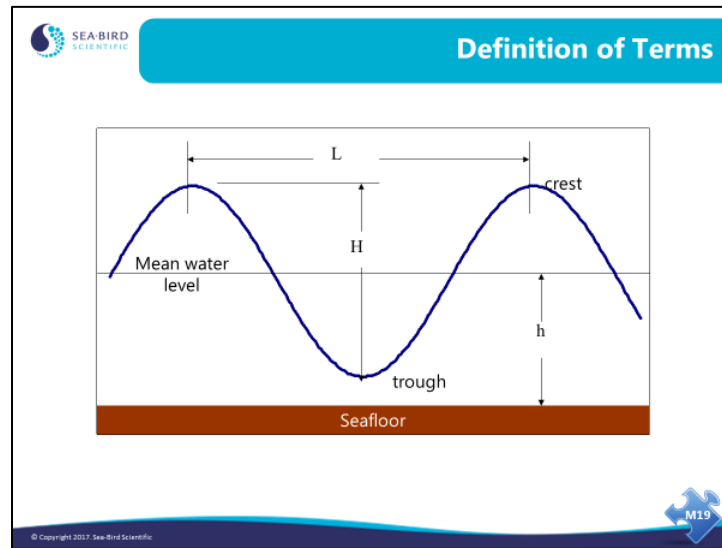
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Some of the parameters that we will be able to determine for a wave burst are:

- 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

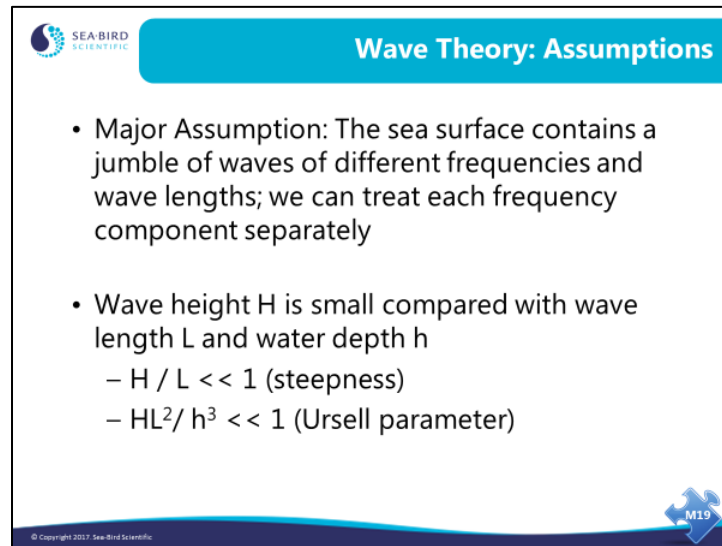
h = water depth in meters

Additional terms:

T = wave period in seconds

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

Measuring Waves: Background (*continued*)



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Wave Theory: Assumptions

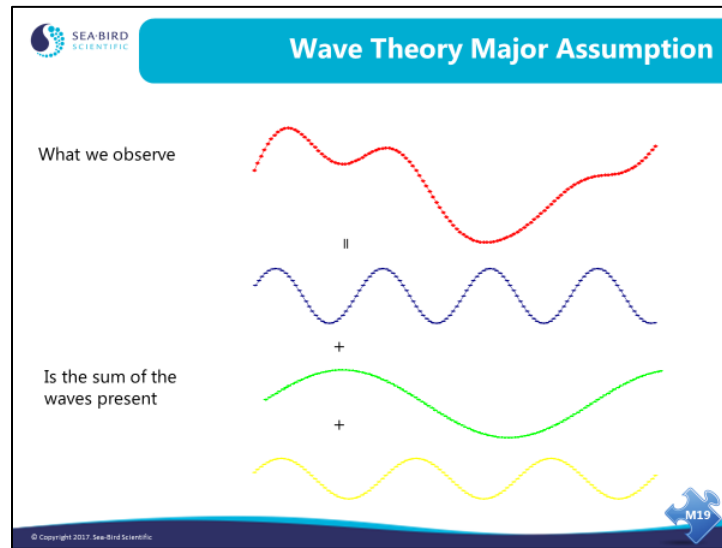
- Major Assumption: The sea surface contains a jumble of waves of different frequencies and wave lengths; we can treat each frequency component separately
- Wave height H is small compared with wave length L and water depth h
 - $H / L \ll 1$ (steepness)
 - $HL^2 / h^3 \ll 1$ (Ursell parameter)

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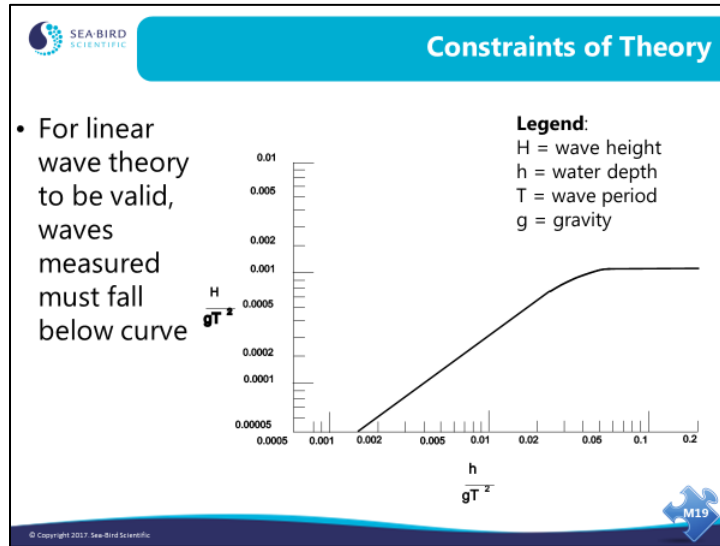
The *major assumption* above is known as linear theory. It supposes that the sea surface we observe is made up of waves of different frequencies, that these waves are superimposed upon one another, and that we can treat each frequency component or wave separately.

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*)


SEA-BIRD SCIENTIFIC Subsurface Pressure Signal Due to Surface Waves

- As a surface wave passes over a subsurface pressure sensor, elevation and depression of sea surface cause a pressure disturbance
- This pressure signal attenuates exponentially with depth

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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*)



Pressure Attenuation vs. Depth

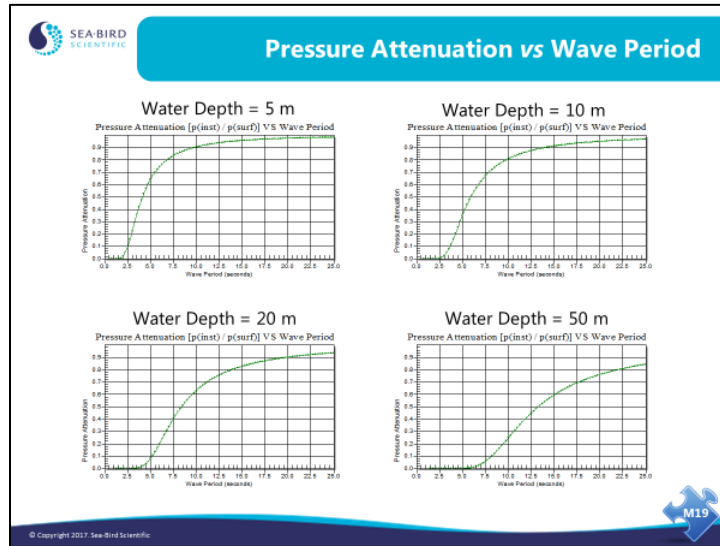
Depth [meters]	Wave Period [seconds]				
	30	20	10	5	2
2	0.996	0.990	0.960	0.844	0.247
4	0.991	0.980	0.921	0.698	0.036
8	0.982	0.960	0.844	0.448	-----
15	0.967	0.926	0.716	0.171	-----
20	0.956	0.901	0.630	0.079	-----
30	0.934	0.853	0.476	0.016	-----
40	0.912	0.806	0.348	-----	-----
50	0.890	0.760	0.247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



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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*)

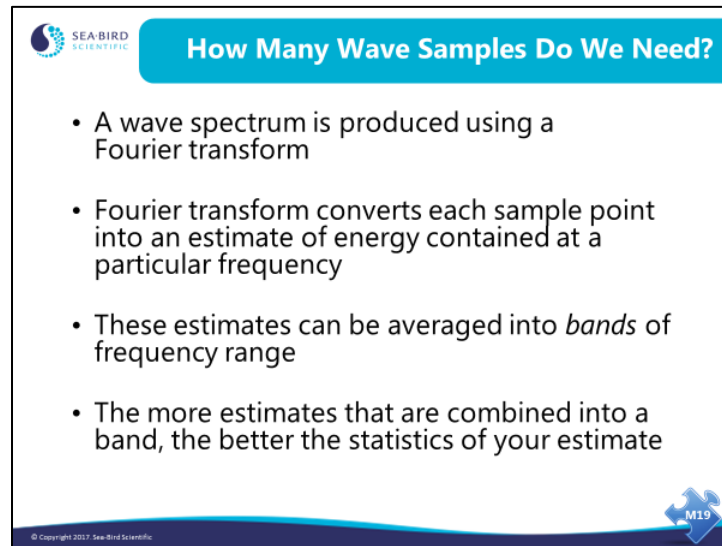
Attenuation Effect On Frequency

- Pressure attenuation is strongly influenced by frequency
- For a sensor deployed at depth z , there is a frequency f_{\max} for which waves with frequencies $f > f_{\max}$ are immeasurable
- Noise occurring at frequencies above f_{\max} is mapped by transfer function into unrealistic wave heights

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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*)



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How Many Wave Samples Do We Need?

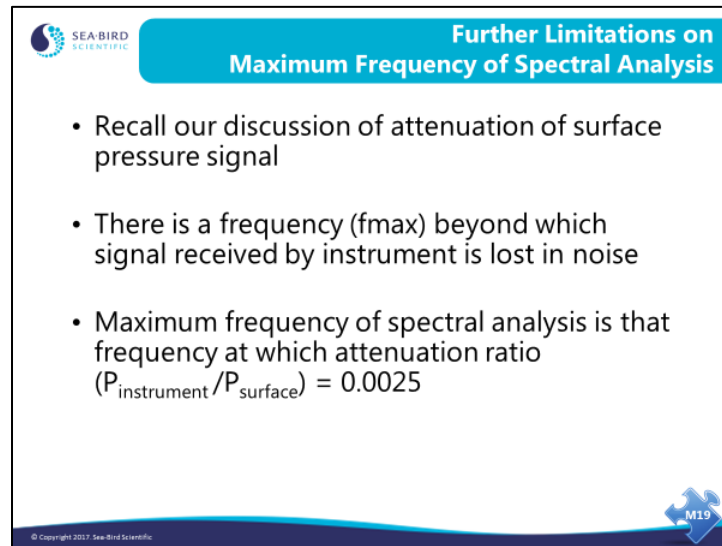
- A wave spectrum is produced using a Fourier transform
- Fourier transform converts each sample point into an estimate of energy contained at a particular frequency
- These estimates can be averaged into *bands* of frequency range
- The more estimates that are combined into a band, the better the statistics of your estimate

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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 $\frac{1}{2}$ 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*)



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Further Limitations on Maximum Frequency of Spectral Analysis

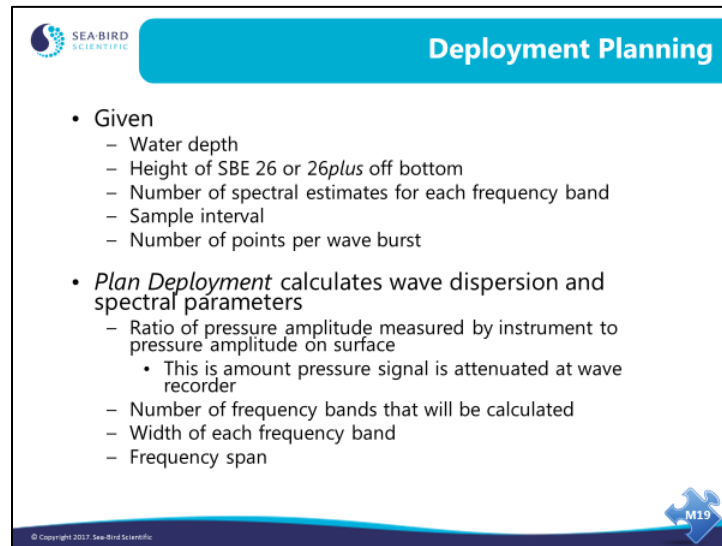
- Recall our discussion of attenuation of surface pressure signal
- There is a frequency (f_{max}) beyond which signal received by instrument is lost in noise
- Maximum frequency of spectral analysis is that frequency at which attenuation ratio $(P_{instrument} / P_{surface}) = 0.0025$

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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



SEA-BIRD SCIENTIFIC **Deployment Planning**

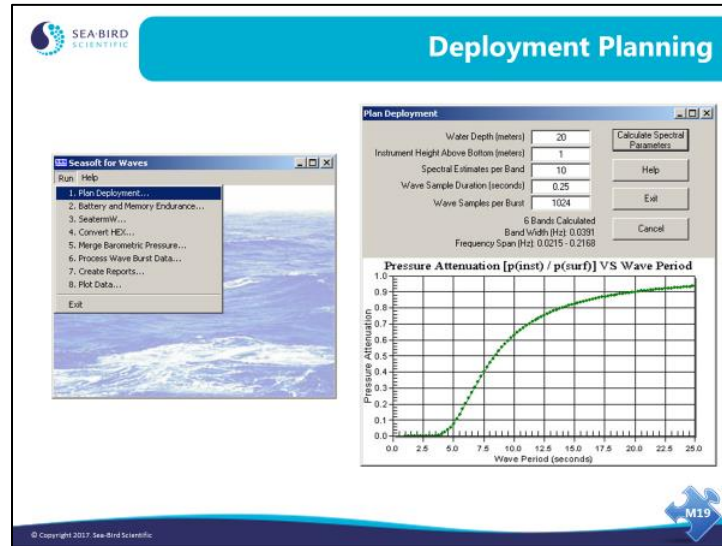
- Given
 - Water depth
 - Height of SBE 26 or 26plus off bottom
 - Number of spectral estimates for each frequency band
 - Sample interval
 - Number of points per wave burst
- *Plan Deployment* calculates wave dispersion and spectral parameters
 - Ratio of pressure amplitude measured by instrument to pressure amplitude on surface
 - This is amount pressure signal is attenuated at wave recorder
 - Number of frequency bands that will be calculated
 - Width of each frequency band
 - Frequency span

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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 26plus 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*)



Some Sampling Examples

- 10 m water, instrument 1 m off bottom, 4 Hz sampling
- For 256 samples / wave burst
 - 2 estimates per band yields 11 bands of width 0.0313 Hz, spanning 0.0234 – 0.3359 Hz
 - 4 estimates per band yields 5 bands of width 0.0625 Hz, spanning 0.0391 – 0.2891 Hz
- For 1024 samples / wave burst
 - 2 estimates per band yields 47 bands of width 0.0078 Hz, spanning 0.0059 – 0.3652 Hz

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Deployment Planning (*continued*)

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Why Doesn't Frequency Range Go any Higher?


- Examples just presented were for a tide gauge in 10 meters of water, fixed 9 meters from surface
- Recall dispersion relation
- As frequency goes up, attenuation goes up
- More samples don't buy us much on high frequency end
- Our low frequency resolution improves as sample number goes up

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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*)



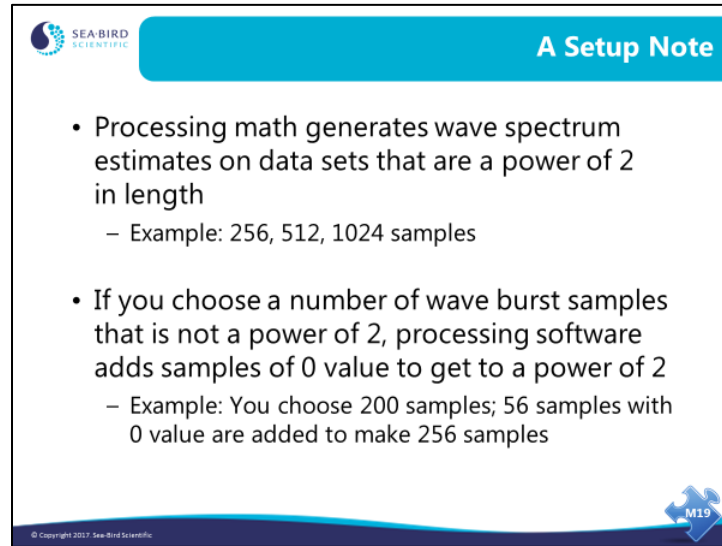
What Are Our Limits on Frequency?

- Maximum frequency you can measure is either:
 - Half the sampling interval (Nyquist frequency) **or**,
 - Frequency where ratio of pressure measured by instrument to pressure at surface < 0.0025

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Deployment Planning (*continued*)



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A Setup Note

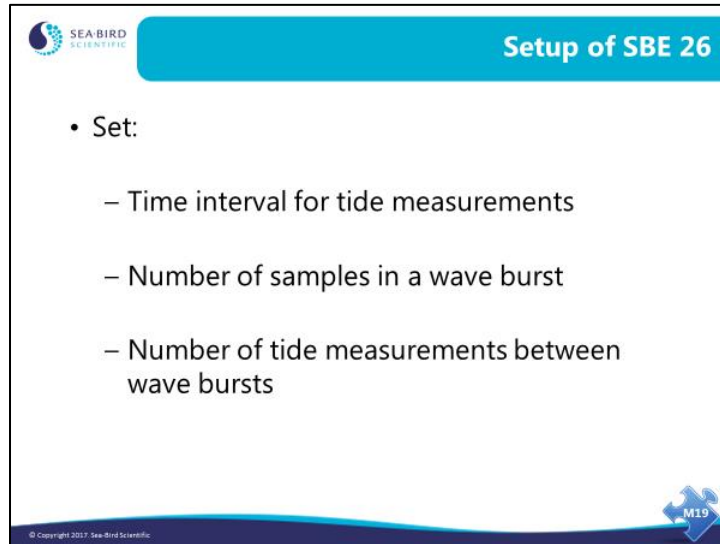
- Processing math generates wave spectrum estimates on data sets that are a power of 2 in length
 - Example: 256, 512, 1024 samples
- If you choose a number of wave burst samples that is not a power of 2, processing software adds samples of 0 value to get to a power of 2
 - Example: You choose 200 samples; 56 samples with 0 value are added to make 256 samples

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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



The slide features a blue header with the SEA-BIRD SCIENTIFIC logo on the left and the title 'Setup of SBE 26' on the right. The main content is a bulleted list of settings. At the bottom left, there is a small copyright notice, and at the bottom right, there is a blue diamond-shaped icon with the number '19' inside.

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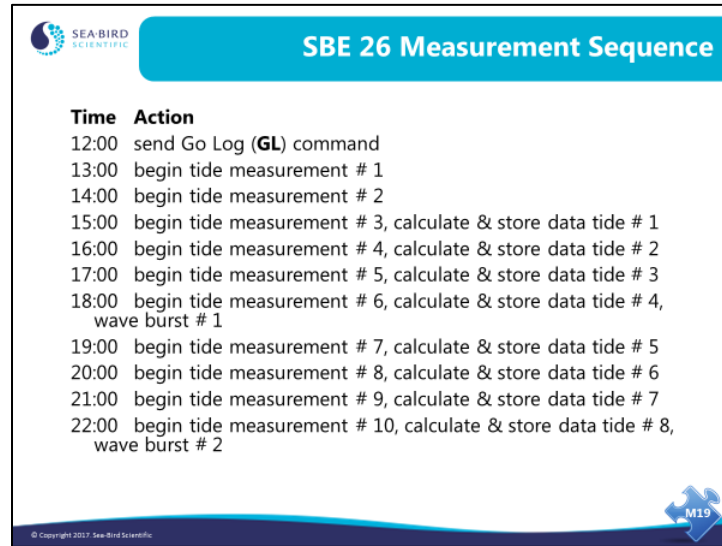
Setup of SBE 26

- Set:
 - Time interval for tide measurements
 - Number of samples in a wave burst
 - Number of tide measurements between wave bursts

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SBE 26 Measurement Sequence

The slide features the SEA-BIRD SCIENTIFIC logo in the top left corner. A blue header bar at the top right contains the title "SBE 26 Measurement Sequence". The main content is a table with two columns: "Time" and "Action". The table lists a sequence of actions from 12:00 to 22:00. At the bottom right, there is a blue diamond icon with "M19" inside. At the bottom left, there is a small copyright notice: "© Copyright 2017, Sea-Bird Scientific".

Time	Action
12:00	send Go Log (GL) command
13:00	begin tide measurement # 1
14:00	begin tide measurement # 2
15:00	begin tide measurement # 3, calculate & store data tide # 1
16:00	begin tide measurement # 4, calculate & store data tide # 2
17:00	begin tide measurement # 5, calculate & store data tide # 3
18:00	begin tide measurement # 6, calculate & store data tide # 4, wave burst # 1
19:00	begin tide measurement # 7, calculate & store data tide # 5
20:00	begin tide measurement # 8, calculate & store data tide # 6
21:00	begin tide measurement # 9, calculate & store data tide # 7
22:00	begin tide measurement # 10, calculate & store data tide # 8, wave burst # 2

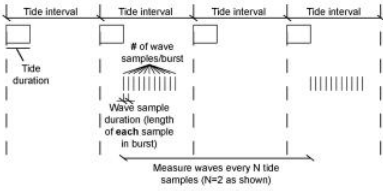
Here is an example measurement sequence for an SBE 26. Tide measurements are an hour in length and a wave burst is done every 4 tide measurements. Because of the frequency counter hardware, a pair of tide measurements is required to calculate the pressure sensed by the SBE 26. Wave bursts are measured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

Setting up the SBE 26plus




Setup of SBE 26plus

- Tide measurement
 - Time interval between tide measurements
 - Duration of tide measurement
- Wave measurement
 - Number of samples in each wave burst
 - Duration of each wave sample
 - Number of tide measurements between wave bursts




The diagram illustrates the measurement sequence. It shows a timeline with four 'Tide interval' blocks, each represented by a small square. Below each interval, a 'Tide duration' is indicated by a vertical line. Within each tide interval, a 'Wave sample duration' is shown as a series of vertical lines representing individual wave samples. A 'Wave sample duration (length of each sample in burst)' is also indicated. A note at the bottom states 'Measure waves every N tide samples (N=2 as shown)', indicating that wave measurements occur at the midpoint of each tide interval.

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


SBE 26*plus* Measurement Sequence



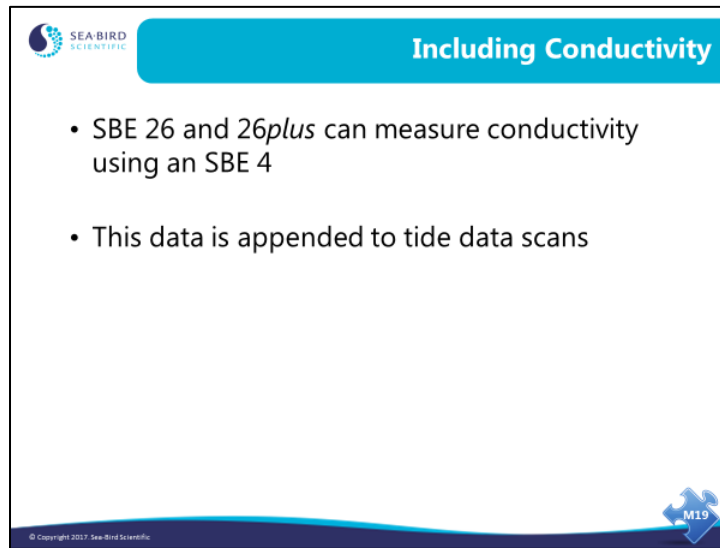
SBE 26*plus* Measurement Sequence

- Because SBE 26*plus* has so many more user-selectable parameters than SBE 26, its measurement sequence is not as straightforward. 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 manual for examples

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Adding Conductivity



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Including Conductivity

- SBE 26 and *26plus* can measure conductivity using an SBE 4
- This data is appended to tide data scans

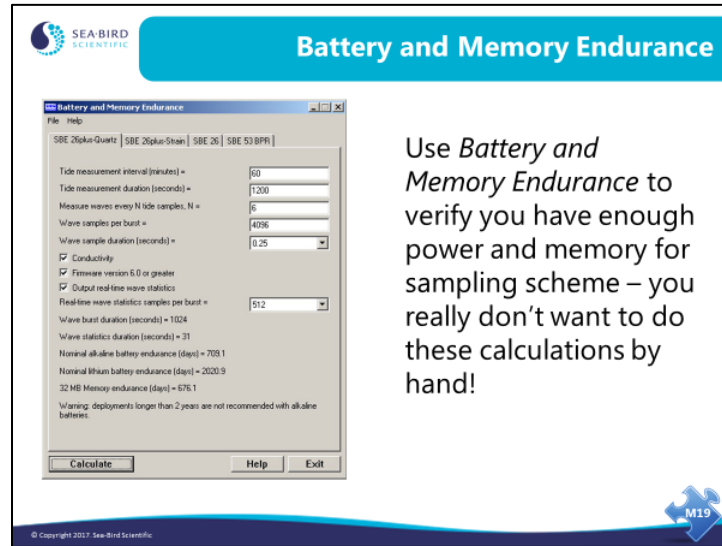
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If integrating a conductivity sensor with the SBE 26 or *26plus*:

- 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 *26plus*.


Battery and Memory Endurance



Use *Battery and Memory Endurance* to verify you have enough power and memory for sampling scheme – you really don't want to do these calculations by hand!

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


Deployment Summary




Deployment Summary

- Use *Plan Deployment* to determine wave burst sample parameters
- Use *Battery and Memory Endurance* to verify you have enough power and memory for sampling scheme
- Install fresh batteries
- Install SBE 4 if conductivity is desired
- Cable to PC serial port
- Run terminal program (*SeatermW*):
 - Set date and time
 - Set sampling intervals
 - Enable conductivity (if appropriate)
 - Enable real-time data if desired (*26plus* only)
 - Check status
 - Start logging (**GL** command for 26; **START** command for *26plus*)
- Put instrument in water

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Recovery Summary




Recovery Summary

- Pull instrument out of the water and rinse it off
- Cable to PC serial port
- Run terminal program (*SeatermW*):
 - Quit logging (**QL** command for 26, **STOP** command for 26*plus*)
 - Verify setup (**DS** command)
 - Upload data
- Convert data (*Convert Hex*)
- Use other Seasoft for Waves modules to calculate wave statistics and display data

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Removing Barometric Pressure from Tide Data



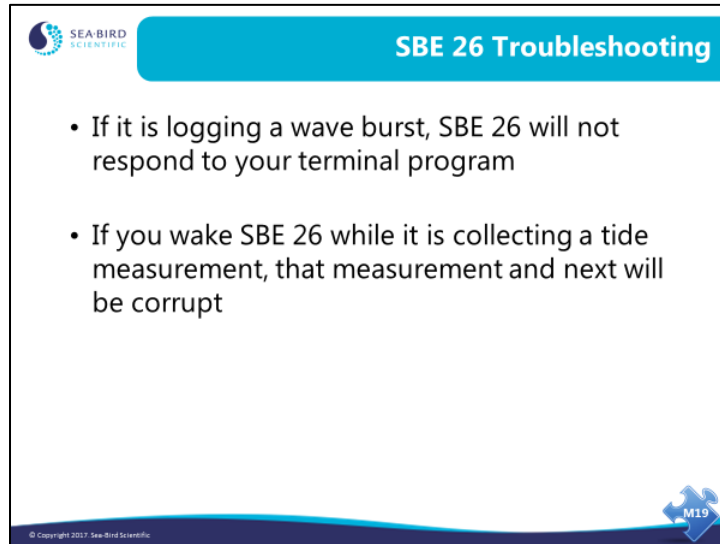
Accounting for Barometric Pressure

- SBE 26 and *26plus* measure absolute pressure
- Absolute pressure is sum of pressure from water above instrument plus barometric pressure
- *Seasoft for Waves* provides software (*Merge Barometric Pressure*) to remove barometric pressure from your tide data set; you can use it after you separate wave and tide files with *Convert Hex*

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Troubleshooting an SBE 26



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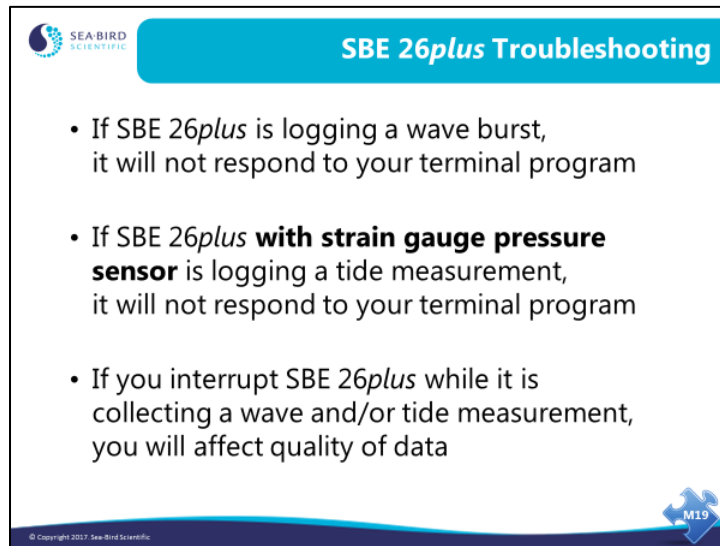
SBE 26 Troubleshooting

- If it is logging a wave burst, SBE 26 will not respond to your terminal program
- If you wake SBE 26 while it is collecting a tide measurement, that measurement and next will be corrupt

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Troubleshooting an SBE 26*plus*



The slide features a blue header with the SEA-BIRD SCIENTIFIC logo on the left and the title 'SBE 26plus Troubleshooting' on the right. The main content area is white with a blue border and contains three bullet points. A blue arrow icon with 'M19' is in the bottom right corner, and a small copyright notice is in the bottom left corner.

SEA-BIRD SCIENTIFIC SBE 26*plus* Troubleshooting

- If SBE 26*plus* is logging a wave burst, it will not respond to your terminal program
- If SBE 26*plus* **with strain gauge pressure sensor** is logging a tide measurement, it will not respond to your terminal program
- If you interrupt SBE 26*plus* while it is collecting a wave and/or tide measurement, you will affect quality of data

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