

Nortek Primers: Getting Started with Wave Measurements

This document is designed for users who consider themselves to know “just enough about waves to be dangerous”. After reading this you will be more capable than dangerous and able to sort out what waves you are really trying to measure and which technology best suits your specific need.

What are waves?

All bodies of water experience waves. These may range from long waves, such as tides (caused by the gravitational forcing of the Sun and Moon) to tiny wavelets generated by the wind’s drag on the water surface. If you were to look at the distribution of energy for waves you would see considerable variability ranging from 12 hours to 0.5 seconds. A significant contribution of this energy is found in the band from 0.5 to 30 seconds and is commonly referred to as *wind waves* (see Figure 1). These are the waves engineers and scientists are primarily interested in when they discuss wave measurements. To accurately measure these waves it often comes down to how well this band is represented by the measurement method.

This 0.5 – 30 second band that defines wind waves has variability that makes characterizing waves non-trivial. To point out the obvious, waves begin both small in height and short in length, created by local winds and grow as a function of wind strength, duration of wind, and distance the wave grows. As a result, the wave environment at a particular location may be composed of a combination of local wind waves from a sea breeze and long waves (swell) generated by storm events hundreds or thousands of kilometers away. What this means to someone trying to measure waves is that they need to appreciate the fact that the local sea state is composed of waves with different amplitudes, periods, *and* directions. Understanding this is the first step to making accurate wave measurements.

How do you measure waves

Waves are random and therefore measuring waves requires sampling over a period of time that will best “capture” or represent the complete sea state. As a rough rule of thumb we try to get 100 cycles of the longest wave we would expect; this means if we expect the longest wave period to be 10 seconds for a particular body of water, then 1000 seconds is the preferred sampling length. The resulting time series of the raw measurements is not particularly useful from a practical standpoint, and therefore needs to be processed to yield parameters that can broadly, yet accurately, characterize the sea state. The most common wave parameters describe height, period, and direction of the wave field and are single values representative of the time series.

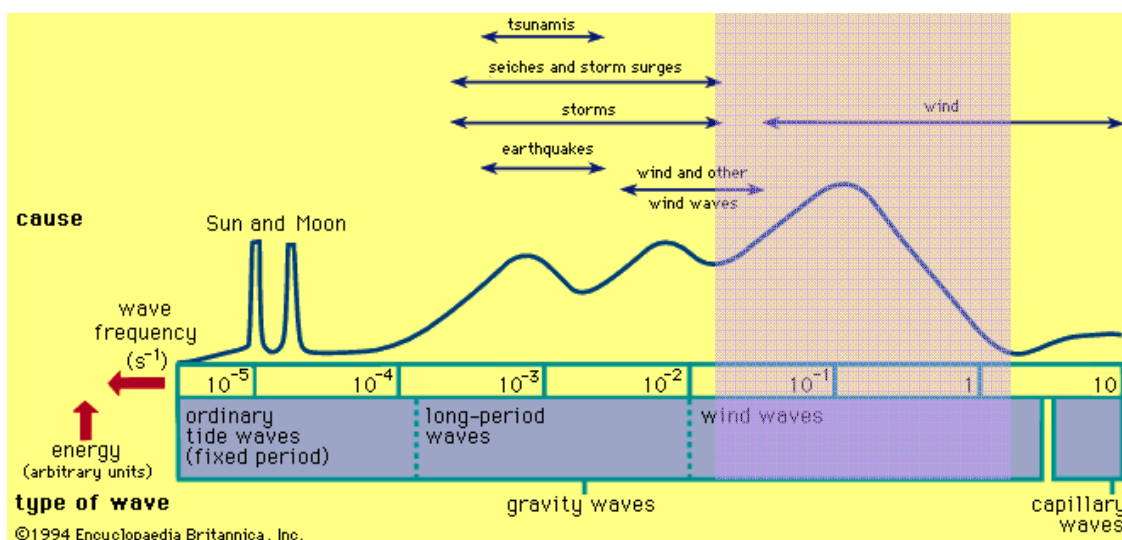


Figure 1 Distribution of Energy. The shaded region from 0.5-30 seconds represents the wind wave band portion of the spectrum that is measured.

Time series analysis

The simplest method for estimating wave parameters is to evaluate the time series of sea surface displacement from a single measurement point. A classic example is using a wave staff in a laboratory to provide a trace of the wave's displacement as it propagates past. The resulting time series analysis determines how far the water surface extends above and below the mean water level. Individual waves can then be determined by where the trace crosses the mean level; this is commonly known as the *zero crossing method* (see Figure 2). Individual waves in the record can then be characterized by period (defined by where it crosses the means water level) and height (defined by the distance from trough to crest between crossings). The result of this exercise is a wave record composed of many waves with a variety of heights and periods.

If these waves are ranked by their height and/or period then the resulting rankings could be used to calculate common estimates of height and period. Two of the more common estimates are *Significant Wave Height* (H_s) and *Mean Period* (T_2). The significant wave height is defined as the mean of the highest 1/3 of all waves in the record's ranking. The mean period is the mean of the all the periods of the record's ranking. Other parameters that may be estimated from the record's ranking are maximum wave height (H_{max}), which is simply the largest measured wave in the record, as well as the mean of the largest 10% of all waves in the record (H_{10}). These latter two parameters are commonly used for coastal design and assessment and are only possible when we have a direct measure of the surface displacement. Indirect measurements of waves can not produce these parameters.

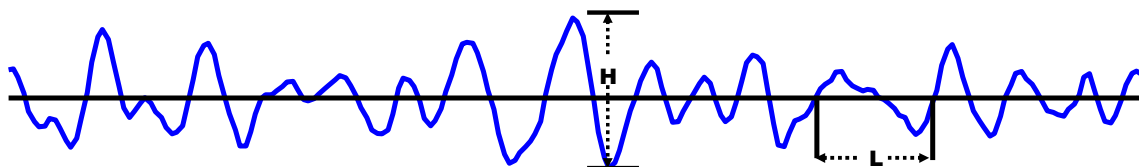


Figure 2 Example of a time series of the surface. Here the zero-crossing technique is used to determine individual wave heights (H) and wave periods (L).

Spectral analysis

The time series analysis discussed above may seem like the appropriate manner to approach wave measurements, however, two common restrictions keep many from succeeding. The first restriction is that time series analysis can also be a little daunting. Second, many wave measuring devices do not have the technology to directly measure the surface displacement and, therefore, do not allow for the possibility of time series analysis. Instead they measure a wave related property such as pressure or velocity and *infer* the sea state from the spectra of the time series (example spectra presented in Figure 3).

Both the ease of interpretation and large number of non-direct measuring instruments has left spectral analysis as the primary method for processing wave results. It provides an enriched collection of wave parameters and also permits directional wave analysis. Wave parameters resulting from spectral analysis include *Peak Period*, *Peak Wave Direction*, and the spectral analogs of mean period and significant wave height, denoted as T_{m02} and H_{m0r} , respectively.

The most complete solution is both a time series analysis and spectral analysis, however, this is often not possible with the majority of instrumentation available today.

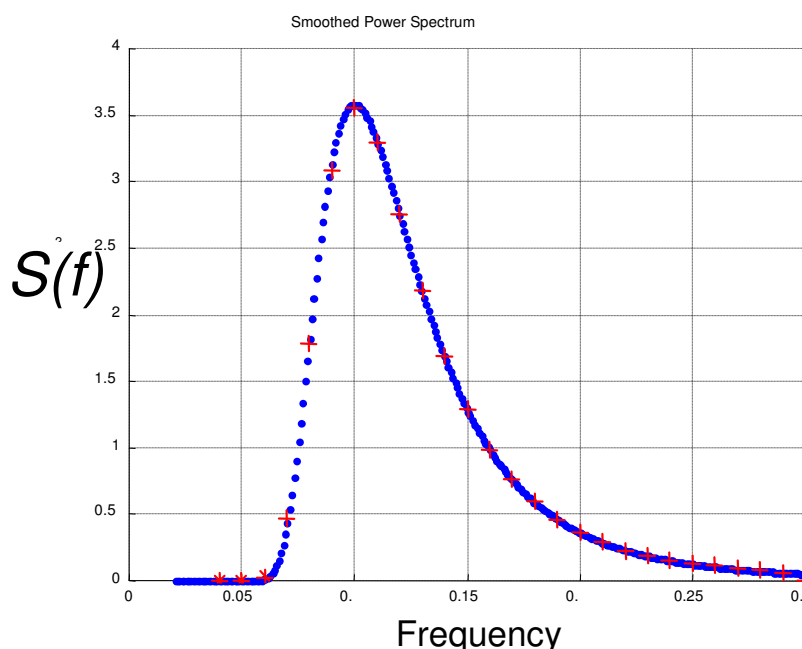


Figure 3 Energy density spectra for a time series. This is ultimately used for estimating wave parameters of height and period.

Subsurface wave properties

Instruments that measure waves from below the surface perform this task in a variety of manners. The majority measure waves indirectly by a related property such as the dynamic pressure or orbital velocities. Before we continue this discussion, for those of you who are not familiar with what happens below the surface when a wave propagates past a point, let us take a moment to explain the basic phenomena.

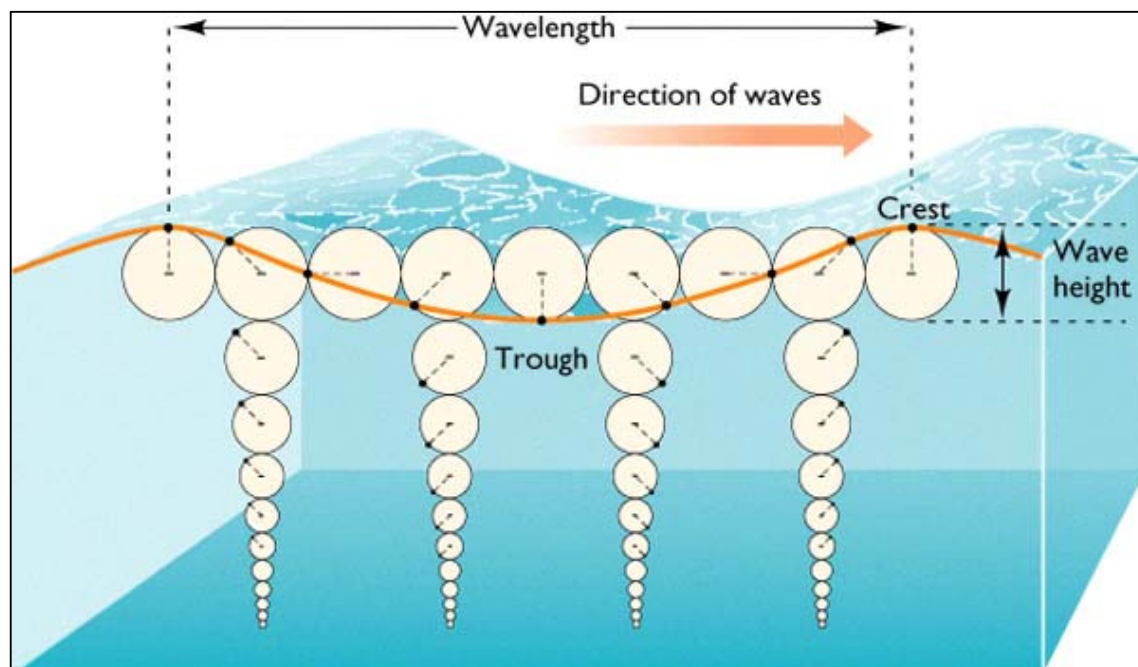


Figure 4 Description of the orbital velocities beneath a wave as it propagates. Note that the orbital velocity also attenuates with depth.

When a wave propagates past a point it creates *local* currents below the surface. These currents are special in the sense that they are changing direction, whereby the crest of a wave will have the effected water below it moving in the direction of propagation and the effected water below the trough is moving in the opposite direction of the propagation. This cyclical motion constructs a circular path in deep water and is often referred to as a *wave's orbital velocity*. An important detail to understand about orbital velocities is that they attenuate exponentially with increased depth *and* shorter wavelength. This means short waves in deep water do not have an orbital velocity signal that penetrates to the bottom.

This is similarly true of the dynamic pressure since it is largely dependent on the presence of orbital velocities, and this means it too experiences attenuation as a function of depth and wavelength. In the following discussion on measurement techniques, you will see the importance of this and the limits this places on deployment depths as well as the wave types (i.e., long verses short) that can be effectively measured.



There is a visual tool that is particularly useful in understanding this, which is found on the web. This tool illustrates the orbital velocities for user specified wave height, wave period, and local depth.

<http://www.coastal.udel.edu/faculty/rad/linearplot.html>

Nortek's wave measurement solutions

As manufacturers of Doppler instruments, you will find that Nortek wave measurement solutions approach the problem from below the surface. The primary advantage of subsurface measurements is that the instrumentation is located safely below the surface where risk of loss by vessel collision, vandalism, or theft is reduced. A combination of measurements are collected from pressure, velocity, and Acoustic Surface Tracking (AST). The following is a description of the different processing methods and associated instrumentation. As an interesting side note, each of the following methods represents a fundamental improvement over the years in the way subsurface wave instrumentation measures waves. The improvement is a result of extending the high frequency range as we try to best cover the 0.5-30 second wave band.

PUV

This method was perhaps the first approach used for measuring directional and non-directional wave properties from below the surface. It dates back to the 1970's and because of its modest requirements for instrumentation and processing, it is still in use to this day.

The name itself is a description of the method as it is an abbreviation of the three quantities measured: **P**ressure and the two horizontal and axial components of the wave's orbital velocity, **U** and **V**. The pressure measurement provides a means of estimating all the non-directional wave parameters and the combined P, U, and V measurements allow for estimating the directional wave parameters. These measurements are made at the instrument's deployment depth and because they are collocated at the same point it is referred to as a "triplet" measurement.

Nortek offers three instruments for PUV measurements. These are the Vector, Aquadopp Current Meter, and the Aquadopp Current Profiler.

The most important thing to understand about the PUV method is that it is limited to (a) deployment depths that are shallow (less than 10-15 meters) and (b) waves that are long (approximately periods 4 seconds or longer). The limitation of only measuring long waves (swell) is the one that should raise a warning flag for those who are interested in the *complete* description of the wave environment. As discussed at the beginning of this document, the accuracy of the solution requires measurements over the entire wind wave band (0.5-30 seconds). Incomplete coverage of the wind wave band risks underestimating wave height and missing peaks in the spectrum. The only way to improve the coverage of the wind wave band is to deploy the instrument in relatively shallow water (i.e. 3 meters depth).



Figure 5 Nortek instruments that measure waves using the PUV method. From left to right (a) Aquadopp, (b) Vector, (c) Aquadopp Profiler.

The reason that the PUV measurement method *cuts-off* at some given period is because the signals that are being measured (pressure and orbital velocity) have a dramatic attenuation that is a function of both deployment depth and wave frequency (period).

Array method

The shortcomings of the PUV instruments prompted the development of a new technique for measuring waves in the early 1990's. This new technique involved employing current profilers to measure orbital velocities closer to the surface where the orbital velocities are less attenuated by depth. As a result the shorter waves could be measured at greater depths. There was an effective doubling of performance; the deployment depth could be doubled or the cut-off period was reduced by half.

This method, however, is not without its shortcomings. A more complex processing method is required since the measurements are no longer collocated but in the formation of an array of measurement cells below the surface. The most common array processing method is the Maximum Likelihood Method. The solution is non-trivial; this means it lacked the "do it yourself" option for processing. Nonetheless, the method has demonstrated very favorable results.

The important detail about the array solution is that the complete wind wave band (0.5-30 seconds) is still not covered and underestimation is possible if the instrument is deployed in typical coastal depths (e.g., greater than 15 meters). The limitation is a result of the horizontal spacing of the velocity cells that construct the array near the surface. When the spacing is greater than $\frac{1}{2}$ of the wavelength being measure, then the solution is no longer valid. Furthermore, this limitation is imposed on both the directional and non-directional solution. Table 1 below indicates the expected cut off periods for various depths.

Nortek’s standard AWAC offers this solution and reduces the limits seen by the PUV method by a factor of two. This solution was a large step forward for subsurface wave measurements; however the complete wind wave band still remained to be resolved to avoiding underestimating wave height. This led to more direct measurements of the surface.

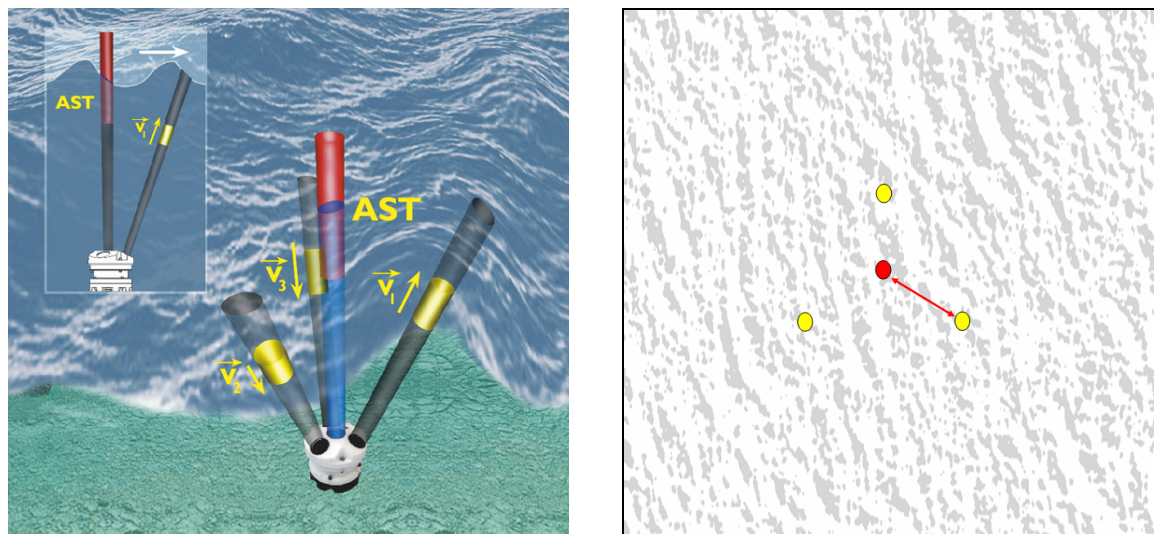


Figure 6 (a) AWAC and the array of measurements cells for orbital velocity measurements (yellow) and Acoustic Surface Track (red), (b) looking down from above at the array of measurements from the AWAC.

Depth	Cutoff Freq	Cutoff Period
5	0.7	1.45
10	0.45	2.20
20	0.32	3.10
30	0.26	3.85
40	0.23	4.35
50	0.20	5.0
60	0.18	5.55

Table 1 Upper frequency limit (cutoff frequency) for array types of measurements such as the AWAC.

Acoustic Surface Tracking (AST)

In 2002, the AWAC was first released with the Acoustic Surface Tracking option. The vertically oriented transducer in the center of the AWAC could now be used to directly measure the distance to the sea surface by use of the simple echo sounder principle. The direct measure (as discussed earlier) has many advantages; the first, and most profound, is there is effectively no depth limit for coastal waters and that the largest possible portion of the wind wave band is covered. The AST measurement also allows for both time series and spectral analysis. This means design parameters such as H_{10} and H_{\max} can be directly measured.

Since the inception of the AST, it has remained the cornerstone to the success of the AWAC. Numerous comparisons have been made with independent and trusted references; the data return has always been near 100% and the estimates of the wave parameters agree very favorably. In short, the AST circumvented all the shortcomings associated with subsurface wave measurement instruments and allows for the best possible coverage of the wind wave band.

Directional measurements with AST

The AST measurement by itself was limited to improving only non-directional wave estimates. This meant that the array method was still used for all directional estimates and therefore limited to the depth dependent array size.

In 2005, Nortek patented a new method for processing wave data from the AWAC with AST. The solution represents a hybrid of the PUV and AST measurements. Wave orbital velocity measurements are still made close to the surface like the array solution but instead of an array the velocities are converted to the axial velocity components of U and V. The other difference is that pressure was no longer used and the AST was used in its place. The result is a solution that permits the AWAC to be mounted on the bottom, or better yet, on a subsurface buoy. This means that when wave measurements are desired in waters where it is not possible to use array solution (60-100 meters deep) the AWAC may be placed on a subsurface buoy and positioned closer to the surface (e.g., 30 meters below the surface). The result is that the AWAC measures directional wave characteristics as if it was mounted on the seabed at 30 meters, yet it has the flexibility to be mounted at depths determined by the subsurface buoy's mooring system.

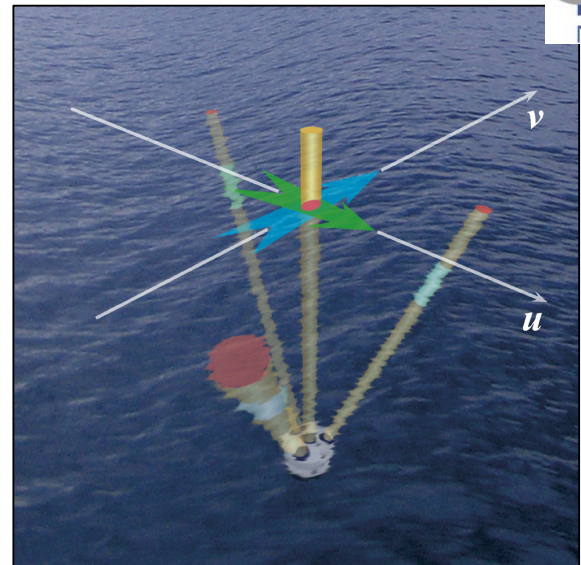
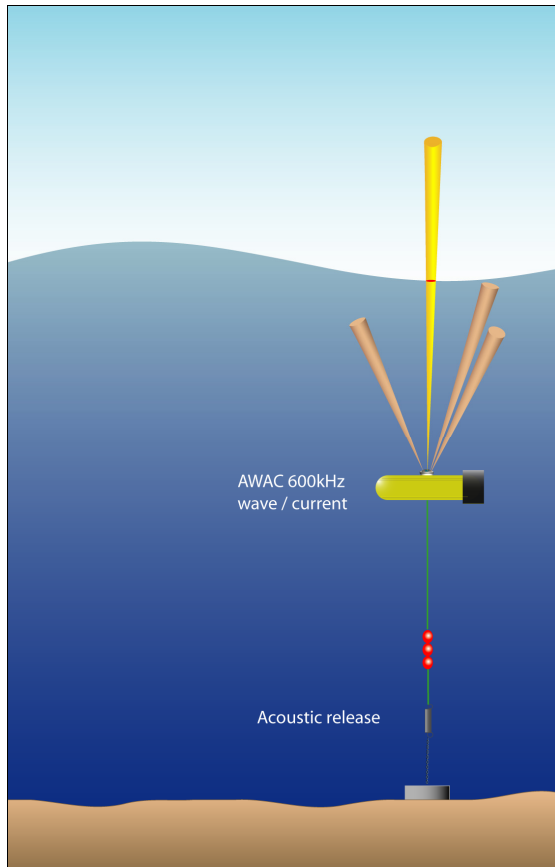


Figure 7 Directional measurements with AST, (a) AWAC deployed on a subsurface buoy and positioned close to the surface, (b) Measurements of AST, U, and V.

Overview

Hopefully, the discussion above has illustrated the differences between measurement methods and the limitations each one is subject to. In the end, the accuracy of the estimate is, to a large extent, dependent on how well the wind wave band is measured. The method that is ultimately chosen should reflect the measurement objectives in the sense of how much of the wave band needs to be represented.

The PUV instruments are fine as long as the water depths are shallow *and* only the longest waves are of interest. As an example, the PUV may be successfully used if one wants to investigate a structure response only to swell in shallow water. An example where there is risk of underestimating wave height is if one wanted to measure the complete wave environment some distance seaward of a harbor entrance.

Experience has shown there are effectively no users who use a standard AWAC without AST. A pure array solution of just velocity measurements is simply too limiting when the option for including the AST measurement is easily included. The value and flexibility that the AST provides means that users tend to evaluate between a PUV solution and the AWAC with AST. PUV measurements tend to be specific to special projects and one must consider the deployment depth and wave band of interest. End users evaluating the most cost effective are encouraged to discuss the possibilities with a Nortek associate.