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Real-time Directional Wave Measurements

Innovative Engineering for Subsurface Acoustic Doppler Current Profilers

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Introduction

Demand for real-time directional wave data has recently surged. However, does the technology exist that will allow us to place an instrument where we wish and still be able to telemeter the data to shore?

Coastal industrial operations, resource management requirements and integrated ocean observation systems (IOOS) have been growing rapidly in importance and number over the past two decades. A key reason for the success of these programs is the ability to provide real-time ocean data products. Directional wave data are among the most important product for safe personnel and vessel operations and are easy for the public to use, appreciate and advocate.

Traditionally, wave measurements have been accomplished from two platforms; surface buoys and bottom-mounted pressure sensors. Surface buoys provide quality wave measurements regardless of deployment depth. Sub-surface sensors are easier to protect from the hazards of surface vessels, rough weather and vandalism. However, due to the attenuation of the pressure signal and wave orbital velocity as a function of depth, traditional bottom-mounted sensors are limited in their ability to resolve high frequency waves.

AWAC equipped with an external battery canister and underwater acoustic modem being deployed in the Gulf of Mexico.

In an effort to provide similarly accurate wave measurements as standard wave buoys, Nortek has developed the AWAC (Acoustic Wave And

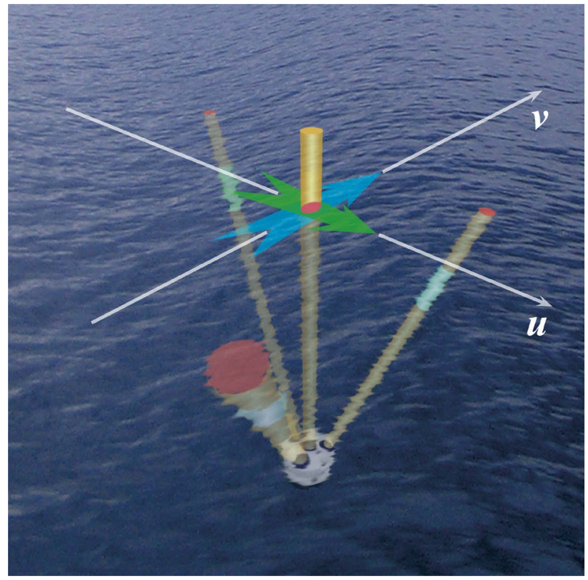
Current) sensor, which remains safely on the ocean bottom. The AWAC is a combination acoustic Doppler current profiler and directional wave gauge. Herein describes the innovative AWAC measurement methodology, wave processing algorithms, data products and real-time telemetry solutions.

AWAC Measurement Methodology

The AWAC makes directional wave estimates by logging a time series of pressure, near-surface velocity and Acoustic Surface Tracking measurements. Typically, wave burst lengths of 512, 1024 or 2048 samples are used and sampling frequency is 1 or 2 Hz. Sampling 2048 points at 2 Hz takes about 17 minutes. These measurements are typically scheduled every 30 minutes to several hours, depending on the application.

To overcome the inherent limitation of signal attenuation in bottom-mounted wave gauges, the AWAC employs a vertically oriented acoustic beam that tracks the surface elevation directly. This method is known as Acoustic Surface Tracking (AST) and may be thought of as an inverted echo sounder. The AST uses a very narrow acoustic beam (1.7°) and can sample at up to 4 Hz, which means that wave energy at frequencies up to 2 Hz may be resolved. The AWAC uses the AST to estimate the frequency spectrum and all non-directional wave parameters from a bottom-mounted position in water depths from 1 – 60 m.

The air-water interface has high acoustic impedance which leads to a strong surface return signal allowing for AST to be a straightforward and robust procedure (Pedersen et al., 2004). The strong surface return signal is enhanced because the AST is measured from a vertical beam, perpendicular to the sea surface. Because the AST acoustic pulse is transmitted at a low power setting, the receiver can detect the surface position even during times of high scattering (i.e. abnormally high suspended sediment concentration and/or bubbles from breaking waves).



A bottom mounted AWAC showing the three near-surface velocity cells and the AST from the vertical center beam. The interpolated velocity components are used in the SUV solution.

Directional information is obtained by along-beam velocity measurements made from near-surface velocity cells. The AWAC collects these data using the three slanted acoustic beams, which are symmetrically positioned about the center and angled 25 degrees from the vertical. This measurement array, which is comprised of the center AST measurement and three symmetrically positioned velocity cells, is intelligently positioned near the surface by using the pressure sensor to determine the approximate sea level position. This allows the AWAC to make accurate measurements even in locations with large tidal ranges.

To validate the AST wave measurements, the AWAC also calculates non-directional wave parameters from the time series of pressure and near-surface velocity measurements. These represent three independent methods of calculating wave estimates.

Directional Wave Processing

MLM Solution

To calculate the wave direction from stationary bottom mounted deployments, the AWAC uses the Maximum Likelihood Method (MLM) solution. The MLM is a general method for estimating directional wave spectra from spatial arrays of wave measurements (Capon, 1969; Kahma et al., 2005). The MLM uses an iterative technique to sweep through frequency and direction to find most probable solution for the direction and frequency spectrum. Measurements considered in the MLM solution may include surface elevation, surface slope, orbital velocity and wave induced pressure.

One clear limitation with the MLM directional solution is the horizontal size of the data array. Spatial aliasing prevents resolving the direction of waves with wavelengths shorter than two times the smallest horizontal separation between any two array elements. For the AWAC, the two closest array positions are the center AST and one of the velocity measurements. The horizontal separation is depth dependent (d * sin 25º) and leads to an upper frequency limit for wave directions. For example, an AWAC mounted at 20 meter depth has an upper wave direction frequency limit of approximately 0.32 Hz.

Practically, this limits bottom mounted instruments to shallow coastal waters. The AWAC could move (or include) the measurement cells closer to the instrument such that they have less horizontal separation. However, this leads to the initial limitations of bottom mounted sensors; the attenuation of the wave signal with increased depth. (Note: Because AST measurement is independent of the wave direction solution, the AWAC does not have the same high frequency limitation for the measurement of non-directional wave parameters).

The natural solution to the upper frequency limitation is to move the AWAC closer to the free surface by mounting it on a subsurface buoy. A submerged platform would allow the AWAC to perform the current profiles and the AST measurements in the traditional way. Unfortunately, assumed rotation of the buoy precludes using the MLM for directional wave processing.

A rotating instrument will corrupt the MLM algorithm, which assumes a stationary array. Since a subsurface buoy is free to rotate, the position of the velocity measurements will change with time and an alternative technique to MLM must be found for the wave directional estimates.

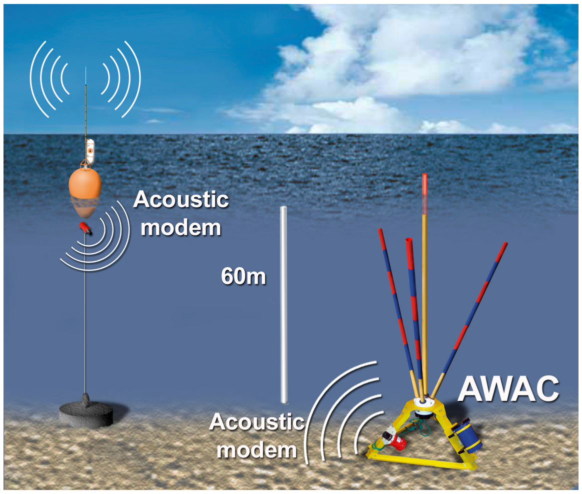
SUV Solution

One approach to solving this problem is to apply a technique similar to the familiar PUV solution (Pressure and orbital velocity U, V), where pressure data is replaced with the AST data. Near-surface horizontal velocity components (U, V) are interpolated to be vertically aligned with the AST. We shall refer to this method as "SUV". Estimates of U and V are possible since the AWAC is equipped with a compass and tilt sensor which is sampled at the same frequency as the beam velocities. Since the interpolation is carried out instantaneously, U and V estimates may be obtained even in the presence of buoy motion (Pedersen et al., 2005).

The analyses of wave direction can thus be computed using simple triplet techniques, where P is replaced with AST and U, V are measured close to the surface to accommodate for the attenuation of orbital velocity of short waves. The SUV solution allows the AWAC to be deployed on the top of a subsurface mooring and directional waves can be measured from any water depth.

NIP Specifications

Traditionally, wave processing has been performed on a standard desktop computer where large amounts of raw wave measurements were acquired and processed. Presently, there is a requirement to have real-time access to wave data through wireless telemetry systems. To address the increasing need for wave data passing through low-bandwidth channels, such as those found in underwater acoustic modems and satellite modems, Nortek developed the Nortek Internal Processor (NIP).



Wireless data telemetry system example. The AWAC is fitted with a NIP and underwater acoustic modem. Data are sent to a surface buoy and then to shore.

The NIP is a scaled down PC running a Windows CE Operating System. Because it is small enough to fit within the AWAC, it does not require any additional pressure housing, cables or battery. The NIP processes the raw data into concise wave estimates, energy spectra, AST time series and velocity profiles. These processed data are considerably reduced (0.1 – 1.0 kilobytes) as compared with the raw wave data (25 – 50 kilobytes).

The NIP may be used in a polled mode where the AWAC may be initiated to conduct a wave measurement when necessary. This makes the system less vulnerable to communication failure (due to technical problems or environmental conditions such as storms). The polled mode simply moves the decision of when to make a measurement away from a predefined schedule and to an "on demand" state. Such a need is applicable when wave data are necessary for critical operations or for tracking the sea-state during storms.

In the world of online systems there is no standard data telemetry or storage method. Various requirements for data formats and types are unique for each application Therefore the NIP was developed so that it can provide data in either binary or ASCII format and so that the user can defined the output format of the data. This allows the AWAC and NIP to be easily interfaced to complex existing data collection and telemetry platforms.

Finally, the power consumption has to be very low to minimize service visits or numerous batteries. Because the NIP is only required to turn on and process the wave data after the data collection burst is over, the processing lasts only about 30 seconds. Clearly the sleep state consumes the most power and this was kept as low as possible. The NIP uses 650 milliwatts when processing and 10 milliwatts in sleep state. This is less than 10% of the power required by the AWAC. Thus the NIP requires a negligible amount of the total power budget.

Data Products

The AWAC wave processing algorithm derives a full suite of data products including: Significant Wave Height, Maximum Wave Height, Mean Period, Peak Period, Mean Direction, Peak Direction, Directional Spread and Unidirectivity Index. Non-directional energy spectra and the full directional spectra of wave energy are also available.

The AST time series supports "wave train" or "zero up-crossing" analysis. From the AST time series, $H_{1/3}$ (the classical definition of significant wave height -- mean of the 1/3 largest waves) and $H_{1/10}$ is also calculated. $H_{1/3}$ is comparable to surface buoy measurements and allows for AWAC data to be directly compared with historical buoy measurements.

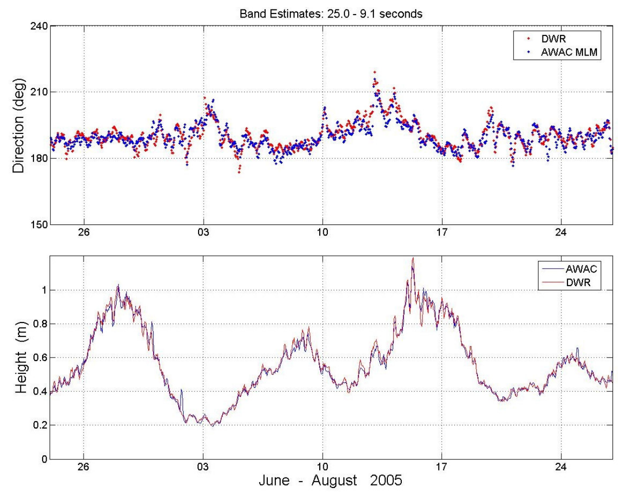
Previous empirical studies have shown that there is a linear relationship between Significant Wave Height (H_s) and Maximum Wave Height (H_{max}). The linear transfer function can vary depending on the measurement methodology and measurement length. A common transfer function is $H_{max} = 1.67 * H_s$. The AST time series allows for a direct "observational" determination of H_{max}; finding the largest wave during the measurement period. The observed H_{max} can be much larger or smaller than the empirical calculation. Differences between derived H_{max} and observed H_{max} of 10 – 20% are common more than 50% of the time. These maximum waves are important to engineers tasked with estimating overtopping limits on offshore structures, coastal breakwaters and levees.

Because the AST measures accurate wave heights at a rate of 4 Hz, high frequency waves (wind chop) can now be well resolved, even from deep water deployments (~20 – 60 m). Bays and estuaries protected from low frequency ocean swell are typically dominated by high frequency wind waves (wave periods of 1 – 3 seconds). High frequency waves are also observed superimposed on low frequency swell in the open ocean. Recent studies have shown that neglecting this high frequency energy (> 0.3 Hz) can lead to under reporting H_s in some case by a factor of up to 50% (Mulligan et al., 2005).

Non-linear and transient waves can be studied from the AST time series in the time domain. Non-linear wave characteristics such as shape and steepness can be observed. Wave patterns from passing recreational and commercial vessels are now measurable.

Data Telemetry & Applications

Typical applications for the AWAC include wave measurements for coastal engineering design studies, beach management, vessel and personnel safety at oil rigs and LNG terminals, boat and ferry wake design and management, wind and wave farms, coastal ocean observing systems and pure research. Real-time data telemetry systems are based on the nature of the application and many choices are available.



Low frequency band-passed data comparison between an AWAC and a Datawell Directional Waverider (DWR) buoy located near Huntington Beach, California.

The most basic system uses a long cable to provide power and data telemetry to the AWAC. For cables over 100 m in length, RS-422 communication protocol is used. A shore-side interface box provides RS-422/232 conversion and 48 VDC power down the long cable. A power control module in the AWAC drops this to a nominal 12 VDC. Raw data are passed through the data cable and the NIP is not required. Cables as long as 5 km have been successfully deployed.

In locations where bottom trawling and recreational boaters (anchors, fishing, etc) are common, long data cables are not desired. Instead, underwater acoustic modems can be used to wirelessly link the AWAC to a surface receive modem. The surface receive modem can be mounted on a shore side structure (i.e. pier or jetty), offshore tower or surface buoy. Final data telemetry to shore is accomplished with RF modem, satellite modem or wireless Ethernet (802.11).

Conclusion

The AWAC is a combination acoustic Doppler current profiler and directional wave gauge. Employing the innovative Acoustic Surface Tracking, the AWAC can measure surface waves directly from a subsurface location. When interfaced with the NIP, this system represents a technological advance that allows users to place equipment where it is most needed and still be able to telemeter the data to shore in real-time.

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