Wave Measurements from a Subsurface Buoy

A new method is described for using the AWAC acoustic Doppler current profiler for directional wave measurements from a subsurface buoy

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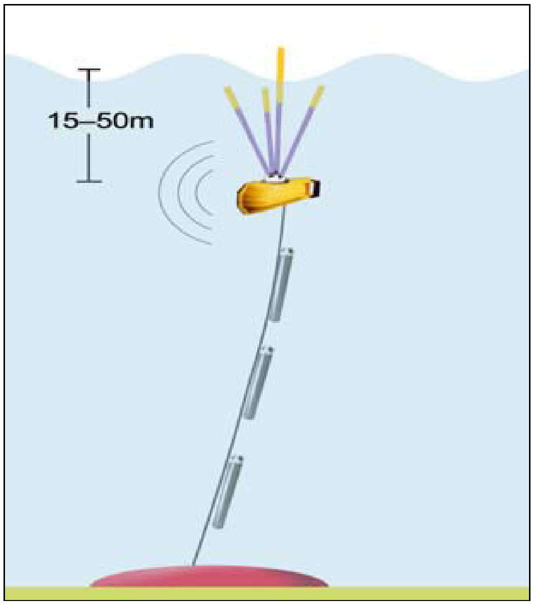
Introduction

A new method for making directional wave measurements using an acoustic Doppler current profiler has been developed. The configuration involves mounting the instrument on a subsurface buoy which allows it to move freely. People familiar with field measurements know that deploying a current profiler from a subsurface buoy is nothing new. However, only current profile measurements have been truly successful with off-the-shelf equipment and processing methods. Until now, routine wave measurements have not been possible with current profilers mounted on subsurface buoys.

Directional wave measurements are challenging when the instrument is allowed to move on a subsurface buoy because classical methods, such as array processing for wave parameters, simply do not work. The directional wave solution requires a new approach, and the most promising solution, known as SUV (Surface tracking and U & V velocity), is a hybrid of existing methods. The new SUV solution requires a vertical beam dedicated to Acoustic Surface Tracking (AST) and therefore it is exclusive to the Nortek AWAC (Acoustic Waves And Currents) system.



AWAC mounted on a subsurface buoy for directional wave measurements. Real time data can be transmitted wirelessly via underwater acoustic modems.

The AWAC is much like a typical acoustic Doppler current profiler and provides current velocity measurements in a vertical profile of discrete cells. However, the AWAC measures waves a little differently because it uses the

AST as the primary means to measure wave energy. This is often a more accurate method because it is a direct measurement of the surface position as opposed to pressure and velocity based estimates which require transfer functions to infer height [1].

Background

Before the details of how the new technique works are described, one may wonder when and why it is advantageous to deploy a wave measuring current profiler on a subsurface buoy. The two most common reasons for this type of deployment are: (1) required measurements in deeper water, and (2) better resolution of high frequency waves. These two reasons are intimately coupled.

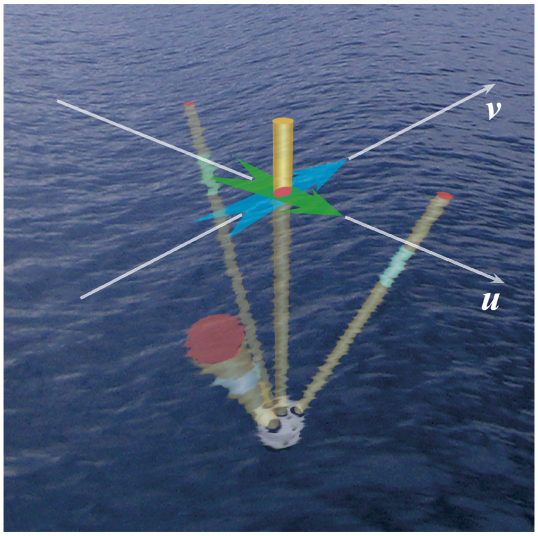
Long term directional wave measurements in deep water environments are intrinsically difficult to achieve. Surface wave buoys can be damaged by storms, ships, ice, and vandalism. Bottom mounted gauges work well for directional measurements in shallow water. However, in depths greater than about 40 m, bottom mounted gauges are not able to provide the directional resolution necessary for most research and commercial requirements.

This depth limitation is not so obvious and has to do with the spatial separation of the measurement cells (known as the "surface array"). When a current profiler is used to measure waves, it measures the wave's orbital velocities near the surface, where their magnitudes are strongest. As the deployment depth becomes greater, so does the horizontal separation between individual measurement cells in the surface array. In order to resolve wave direction at any given frequency, the horizontal separation of individual measurements in the surface array must be less than half a wave length. This aliasing presents a spatial Nyquist limit and leads to a "cutoff frequency" where wave directions cannot be resolved. For example, a gauge deployed 40 m below the surface has a directional cutoff frequency of about 0.22 Hz (4.5 seconds). This means the gauge will not be able to resolve directions from waves shorter than 4.5 seconds.

At offshore sites, the ability to mount a wave gauge on a subsurface buoy permits the instrument to be close enough to the surface for high quality wave measurements yet be removed from the dangers of exposure at the surface.

SUV Method Description

Traditionally, current profilers have used a type of array processing for estimating wave parameters. This is an adequate solution for a bottom mounted instrument, but it is not suitable for a subsurface buoy. The array processing uses the time lags of the measured wave orbital velocities to estimate wave direction. However, if the position of the measurements in the surface array are not stationary (due to buoy motion), then array processing becomes mathematically impossible to solve and cannot be used. Nortek developed the SUV method to solve the problem of directional wave measurements from a moving subsurface buoy [2].



AWAC shown with three velocity cells and one AST measurement. Beam velocities are transformed to U and V components for the SUV solution.

In order to calculate wave direction from a subsurface buoy, one needed a method that measured wave orbital velocities near the surface (where they are far less attenuated), permitted free motion of the subsurface buoy (unlike standard array methods), and included AST for accurate wave energy measurements. The SUV method for the Nortek AWAC fulfills all three of these requirements. As the name suggests, it has similarities to the classic PUV (Pressure and U & V velocity) method in that it is a triplet type directional solution.

The SUV triplet measurement is composed of the AST measurement and the two co-located estimates of the horizontal orbital velocities, U and V. The estimates of U and V are calculated by first measuring along beam velocities, then converted to an Earth referenced U and V using a standard coordinate conversion. This requires making simultaneous measurements of heading, pitch, and roll at a similar sample rate as the velocity measurements (1 Hz). The result is an interpolated version of the true near-surface U and V components of the wave's orbital velocity.

Results from the North Atlantic

The SUV method performed well for a bottom mounted AWAC when compared to the classic array solution as well as against wave buoys [3]. However, in order to fully test the subsurface buoy configuration, Nortek teamed up with researchers at Bedford Institute of Oceanography and deployed two different types of subsurface buoys in the North Atlantic Ocean offshore of Lunenberg Bay, Nova Scotia, for a period of two months (Oct-Nov 2006).

This was a very energetic period with wave from three tropical storms. The two buoys were deployed next to a Directional Waverider (DWR) surface buoy, which served as an independent reference. One subsurface buoy was a spherical type (Sphere) provided by Mooring Systems, Inc. (Cataumet, Massachusetts) and the other subsurface buoy was an asymmetrical submarine-shaped buoy (SUBS) provided by Open Seas Instrumentation (Musquodoboit Harbour, Canada). Both moorings were deployed with a 12 m cable and anchored to the bottom. The total water depth was 32 m, which positioned the subsurface buoys nominally 20 m below the surface.

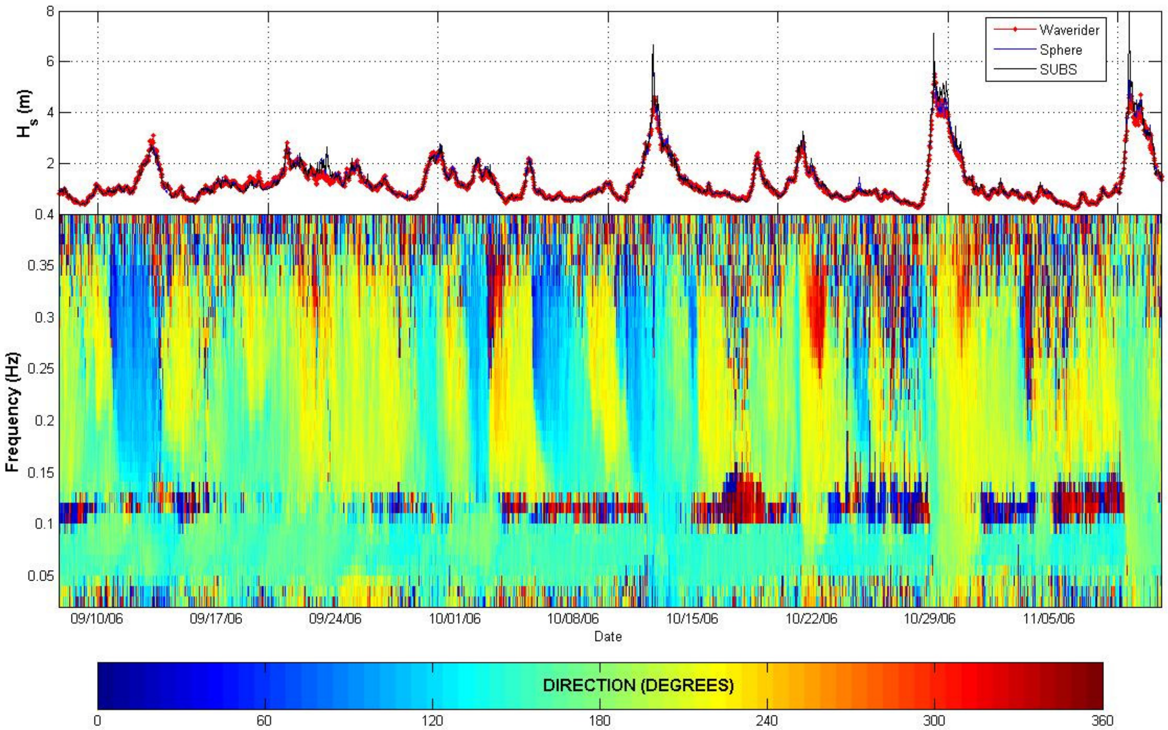
Acoustic Surface Tracking (AST) Performance

It was suspected that excessive subsurface buoy motion or large tilt could lead to reduced AST performance. Quality controls in the wave processing software monitor the AST measurement by searching for "bad detects" (i.e. outlier points). When the number of bad detects exceeds 10% of the total AST samples in a single wave burst, then the AST for the given wave burst is deemed of poor quality and not used (in this case, independent measurements of pressure and near-surface orbital velocity are used for the non-directional estimates of wave energy).

Results show that the AST performed very well and therefore estimates of significant wave height (H_s) and peak period (T_P) were accurate. This was true for the entire two month test period, even with H_s estimates of greater than 4 m during three different storms. Both buoys had only 10 bursts out of more than 1,500 bursts that were deemed unusable because the AST had too many bad detects. For the Sphere buoy, 96% of the wave bursts had less than 1% AST bad detects. For the SUBS buoy, 94% of the bursts had less than 1% AST bad detects. Not only was the AST robust for both systems, but robustness was also quite similar to traditional bottom mounted systems, confirming that the AST functions well even on a moving platform and in large waves.

Direction Estimates

Directional data from both subsurface buoys agreed well with the independent DWR measurements [4]. Most importantly, and perhaps contrary to common expectation, the directional estimates were accurate across all frequency bands during times of increased wave energy. However, it was found that each buoy had a specific frequency band of increased directional uncertainty at certain times. The Sphere showed directional uncertainty in a band centered on 0.11 Hz (9 seconds) and the SUBS showed uncertainty in a band centered on 0.05 Hz (20 seconds).



Significant wave height for both AWAC's and DWR. Directional spectrogram from one AWAC (Sphere). Note band of directional uncertainty centered on 0.11 Hz.

A band-pass analysis was used to evaluate the accuracy of the SUV method. There are many common bands where all three instruments functioned properly. For statistical comparison of wave direction, the Sphere versus the DWR and the SUBS versus the DWR both had a R^2 value of 0.99, mean difference of 1 degree and standard deviation of 6 degrees for the band of short waves (4-7 second band). The SUBS versus the DWR had a R^2 value of 0.92, mean difference of 4 degrees and standard deviation of 8 degrees for the 7-10 second band. The Sphere versus the DWR had a R^2 value of 0.86, mean difference of 0 degrees and standard deviation of 6 degrees for the 10-33 second band.

Subsurface buoys oscillate back-and-forth much like an inverted pendulum and the calculated characteristic frequency of each mooring system corresponds directly to the unique frequency bands having increased directional uncertainty. The characteristic frequency is a function of several variables including buoyancy and mooring line length [5]. The characteristic frequency was different between the two subsurface buoys tested due to their different buoyancies (Sphere = 215 kg, SUBS = 45 kg). A properly designed mooring system can move the characteristic frequency outside of the wave band and thus prevent unwanted effects of motion on the directional solution over all bands of importance.

Additional Applications

In addition to wave measurement at offshore sites, there are several applications in both deep and shallow waters for which making wave measurements from a subsurface buoy is advantageous.

Extreme latitudes with seasonal ice

Surface wave buoys are often removed for the winter in extreme latitudes where seasonal ice presents a threat. Wave measurements from a subsurface buoy allow continuous collection of data during the winter. Further, the AWAC has a special diagnostic AST measurement that allows for estimates of ice keel or thickness.

Soft, moving and irregular bottoms

One unexpected application of the SUV method is that an AWAC may be mounted on a subsurface buoy with a very short mooring line. This allows the AWAC to be deployed safely and avoid burial in coastal areas with moving sand waves or very soft bottom types. This also simplifies deployments in regions where the bottom is irregular and deploying a bottom frame is challenging.

Real time data

For real time data requirements, the AWAC can be connected wirelessly to a surface structure or buoy via underwater acoustic modems. Depending on local hydrographic conditions, these modems may have a horizontal range of up to several kilometers.

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