Subsurface wave measurements taken to new depths

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Abstract:
During the beginning of 2008, Nortek collaborated with SMHI (Swedish Meteorological and Hydrological Institute) for a marine environmental site survey off the western coast of Sweden in support of an engineering project where a new gas pipeline will be constructed. The collaboration served two objectives. The primary was to collect marine environmental data, namely currents and waves off the coast of Lysekil, Sweden. For Nortek, this also served as an excellent opportunity to demonstrate the capabilities of what represents the state of the art in wave measurements for acoustic Doppler instruments.

Nortek has made significant strides over the last few years with developing technology that permits deploying wave measurement instruments in increasingly deeper waters without compromising accuracy. This latest development is measurement of waves and currents from a subsurface buoy.

This document provides a synopsis of the current and wave measurements off the coast of Lysekil. It also represents yet another comparative study of the performance of wave measurements from a subsurface buoy which employs Nortek's patented SUV measurement method.

Figure 1. Deployment of a SUBS and AWAC (upside down) similar configuration to that used at Lysekil, Sweden.

Keywords:

AWAC, Subsurface Buoy, Wave Measurements, Currents, Doppler.

Introduction:

The AWAC is traditionally deployed on the bottom where it can measure both waves and currents. The primary benefits of this approach are that a single instrument has dual measurements of waves and currents, and that it provides the comfort that it is out of harms way; as opposed to surface instrumentation which is subject to the risks at the surface. The drawback of bottom mounted Doppler profilers for wave measurements is that they are limited to coastal waters where the profiling range and wave measurement from the sea bottom are limited to depths less than 60 meters. Many of those performing site environmental surveys do not have the luxury of specifying the deployment depth, and must conduct measurements at a specific location. As a result wave measurements are often made with a wave buoy and current measurements are performed with an independent instruments and/or mooring.

Nortek has solved this problem by developing a special wave measurement technique, which permits the AWAC to be mounted on a subsurface buoy which is allowed to rotate freely. The subsurface buoy provides the benefit of positioning the AWAC closer to the surface where the accuracy of wave and current measurements are far less compromised. The traditional array method is not an option in this deployment configuration since the rotation of the buoy leads to a non stationary array. The resulting inverse solution, where the array measures are used, is not possible. Nortek solved this problem by developing a special wave measurement method. This method is referred to as the SUV method and was patented by Nortek in 2008.

The SUV method may be briefly be described as a hybrid of existing wave measurement technologies where the Acoustic Surface Tracking is used for the non-directional estimates and interpolated measures of velocities near the surface are used for the directional estimates. A more complete description of the method may be found in Pedersen, Lohrmann, and Krogstad (2003).

There have been several tests to confirm the validity of this measurement technique. The fist was conducted off the coast of California where data from a bottom mounted AWAC was processed using both array methods and the new SUV method. This data was compared to a co-located Waverider buoy. Results of this comparison can be found in Pedersen, Siegel, and Malzone (2005).

The SUV method underwent its first buoy-mounted comparison during the autumn of 2006 off the Atlantic coast of Canada. During a 2 month deployment two different subsurface buoys were tested (SUBS torpedo style and MSI spherical buoy). A Datawell directional Waverider was located nearby as a reference. During this two month period, the instruments saw significant wave heights greater than 4 meters on three separate occasions. The results from this test demonstrated that the acoustic surface tracking (AST) was robust during a wide range of wave conditions and that the directional and non directional estimates were in very good agreement with the Waverider. The exception was that the directional estimates were corrupted by buoy motion when wave energy was low; this result was determined to be wholly dependent on the mooring/buoy natural response. Poor wave directional estimates were noted in narrow band centred at the characteristic frequency of the mooring system. The mooring system response and the results of the buoy mounted AWACs are discussed in detail in references Pedersen, Siegel, and Wood (2007) as well as Pedersen and Siegel (2008).

The mooring system was fortunately not representative of a typical mooring design for an AWAC mounted on a subsurface buoy. The mooring length was 12 meters for a location with 30 meters total depth. In a typical application of the SUV method, a mooring would be greater than 50 meters in length and the natural response would be out of the wave band. Again it is worth pointing out that for depths less than 60 meters an AWAC can be mounted on the bottom.

The deployment for Lysekil represents the last chapter in the series of a rigorous testing of this measurement method. The Lysekil deployment represents the intended deployment configuration and the results demonstrate the performance one can expect. Once again there was a Waverider nearby for comparison.

Deployment Description:

SMHI (Swedish Meteorological and Hydrographic Institute) was contracted to conduct a marine environmental survey (currents and waves) off the coast of Sweden in support of the installation of a gas pipeline that will extend from the North Sea to Lysekil, Sweden (Figure 2). The survey included several AWACs; one of which was deployed on a subsurface buoy. The 600 kHz AWAC deployed on a subsurface buoy was located at 120 meters total depth and the mooring was 90 meters in length (Figure 3). A SUBS buoy was used for the deployment, and a Datawell Waverider was located nearby and served as a reference. Measurements were collected for a period of more than 2 months during February-April, 2008. The Waverider data was offline for a period of one week and explains the noted gap in the comparison data.

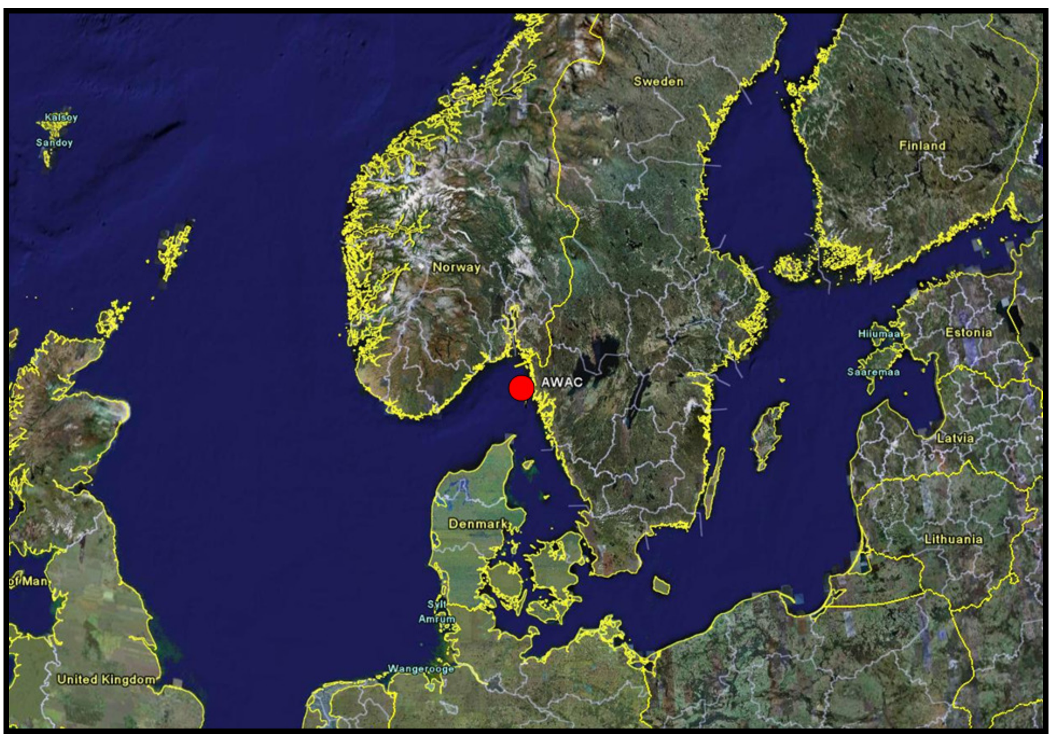

Figure 2 AWAC location (red marking). 58 12.28 N, 10 58.72 E. Total depth was 120 m.

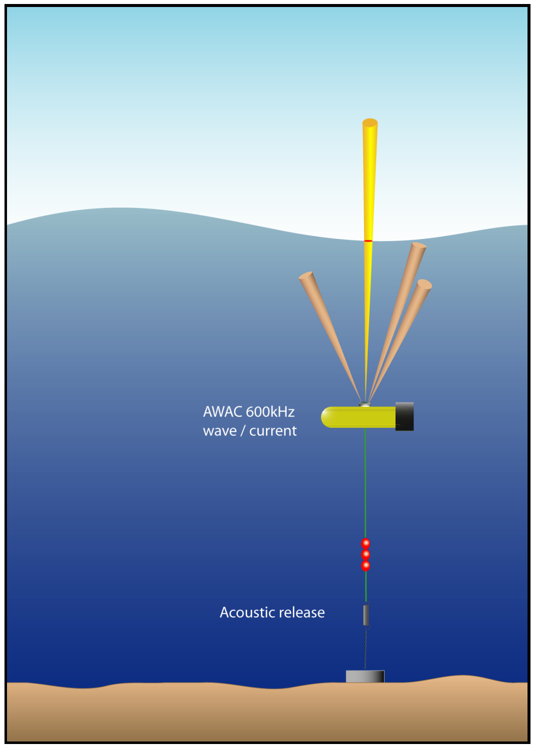

Figure 3 Mooring configuration for 600 kHz AWAC mounted on a SUBS buoy. The four beams projecting away from the AWAC are the three slanted beams for velocity measures and a vertically oriented beam for Acoustic Surface Tracking (AST). The total depth at the Lysekil site was 120 meters and the mooring length was 90 meters.

Currents were in excess of 1 m/s and significant wave heights exceeded 4 meter on four separate occasions. Currents were consistently to the North. The large currents and mild buoyancy of the SUBS (42 kg net) led to occasional draw down from 32 to 50 meters. Apart from the fact that a different portion of the water column was profiled, the drawdown did not have any negative effects on the quality of the waves or currents estimates.

Performance of AWAC – SUBS:

The buoy's attitude was measured during the wave burst measurements with a sampling rate of 1 Hz. The standard deviation of the roll and pitch for each burst throughout the deployment is presented along with heading information in Figure 4. The tilt measurements are actually a combination of tilt and acceleration since the sensor can not decouple these two quantities. Wood et al. (2006), demonstrated in a similar test that acceleration accounts for as much 90% of the tilt measurement. The buoy, as an instrument platform, was therefore more stable during the wave measurements than the attitude data would suggest.

The characteristic response, which is discussed in Pedersen, Siegel, and Wood (2007) as well as Pedersen and Siegel (2008), is presented in Figure 5 for a range of mooring lengths. The response for the mooring at Lysekil is indicated by the red circle. The response is estimated to be greater than 35 seconds and this is out of the wave band of interest (indicated by the light blue shaded region). This means that even if there is pendulum like effect of the mooring as noted in the North Atlantic test (discussed in Pedersen and Siegel, 2008), the motion would not affect the directional estimates.

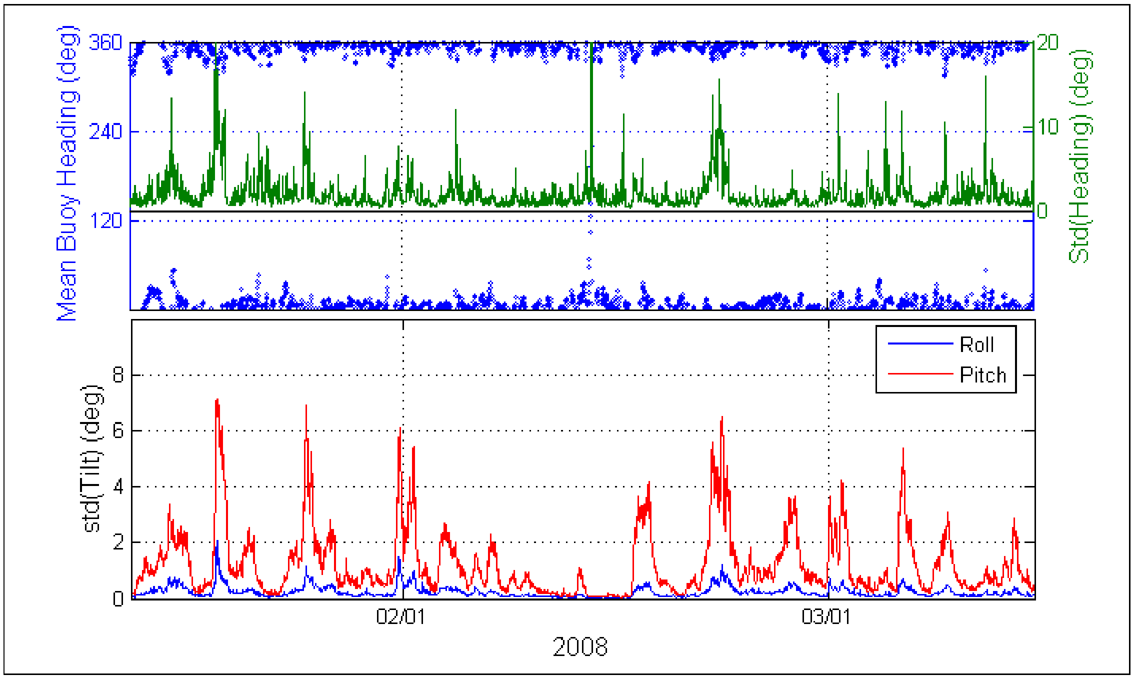

Figure 4 Buoy Attitude during wave burst measurements. (a) Buoy mean heading (blue – axis left) and standard deviation of heading (green-axis right) during the burst. (b) Standard deviation of tilt.

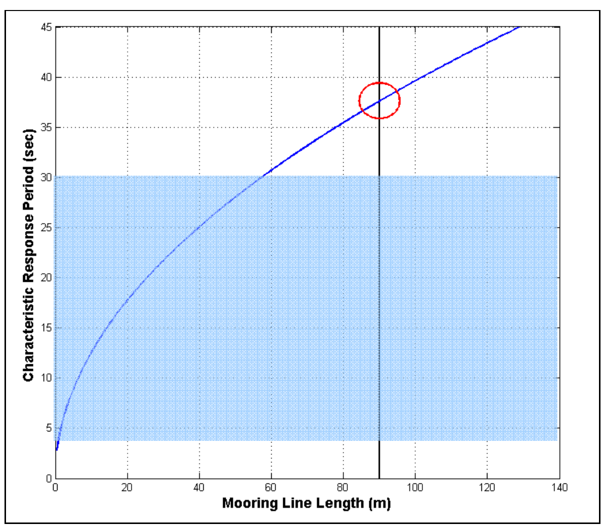

Figure 5. Characteristic response estimated for the SUBS buoy for a range of mooring lengths. The shaded region indicates the full range of the wave band that is desired to measure. The mooring at Lysekil was 90 meters long and as a result had a characteristic response of approximately 37 seconds (red circle); this is safely outside the wave band of interest.

Wave Data:

The performance of the AST from a subsurface buoy was an initial concern during the early development of the SUV method, however results for the comparative study on the Atlantic coast of Canada demonstrated that the performance was similar to a bottom mounted AWAC. The AST in a wave ensemble (“burst”) is deemed valid if less than 10% of the samples for a given AST time series were characterized as “outliers” and discarded. A typical deployment experiences approximately 1% of the wave bursts with discarded AST time series. This was the result from the tests in the North Atlantic Pedersen and Siegel (2008). No wave bursts in the Lysekil deployed exceeded the 10% threshold and therefore all AST time series were valid. Figure 6 presents the percentage of bad detects (“lost data”) for each of the wave bursts. Data for significant wave height and instrument depth (mean pressure) is presented as well to show any correlation. We note that an increase in bad AST detects from near zero to approximately 5% is associated large waves which are possibly breaking, and not with the draw down of the buoy.

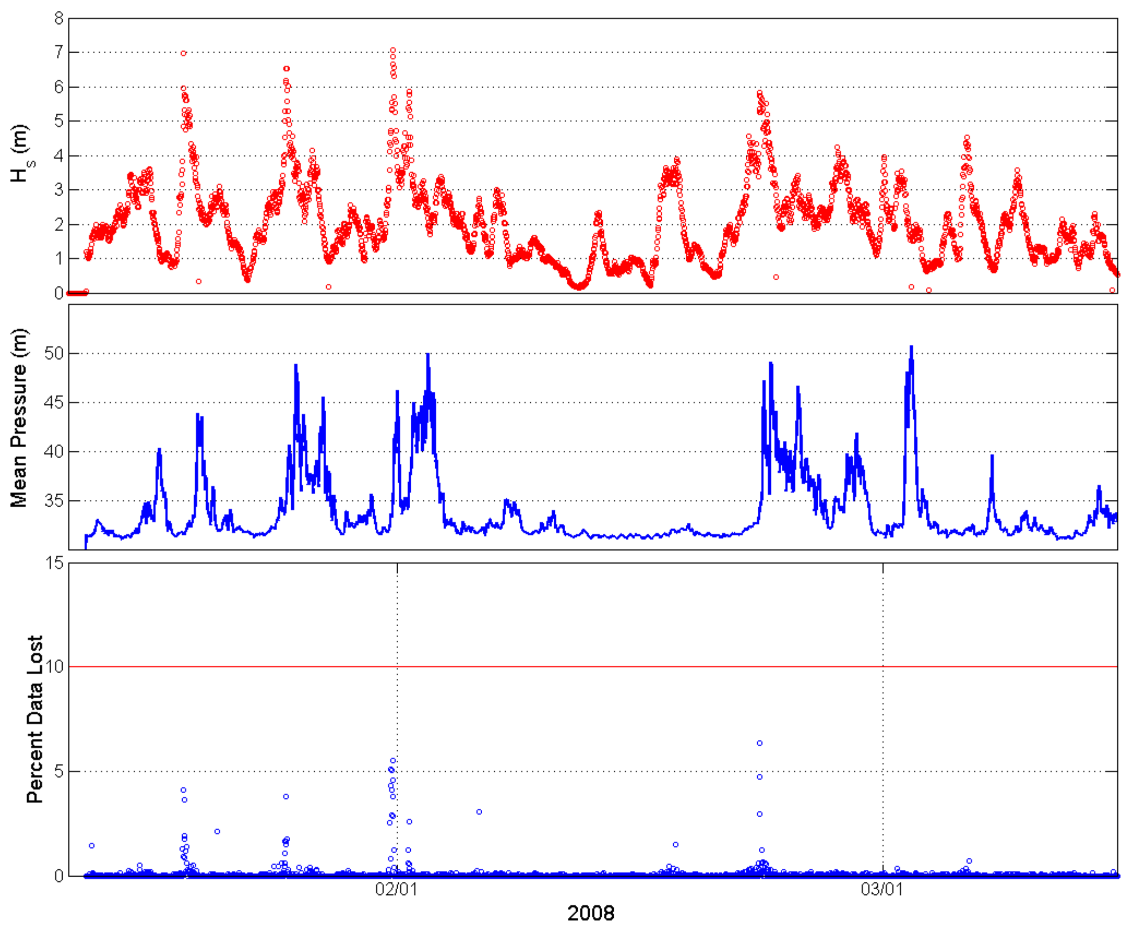

Figure 6. AST performance: (a) Significant wave height (H_s), (b) Draw down depth of buoy, (c) Percentage of data loss resulting from bad AST detects, red line indicates threshold to discard AST time series in wave processing.

A comparison of wave estimates between the buoy mounted AWAC and the Datawell Waverider is presented in Figure 7. Similar to the North Atlantic test of 2006, there was very good agreement for the non-directional estimates of significant wave height and peak period. What was different this time was the performance of the directional estimates which was also very good; this was not the case for the North Atlantic test of 2006 when the mooring system's natural response corrupted directional estimates during mild sea states. The deployment at Lysekil used a mooring which had a characteristic frequency out of the wave band and therefore the results were uncorrupted by the subsurface buoy's motion.

A composite of the wave estimates is presented in Figure 8. This final figure represents a summary of all wave estimates. The total energy is presented by the significant wave height. The distribution of wave energy is shown in the frequency diagram; this is a contour plot of the energy which is normalized for each burst. The result shows more detail structure during a variety of sea states. A plot of the buoy draw down is also presented to show the limited effects of strong currents on wave measurement performance.

The directional spectrogram shows interesting structure where waves are primarily from the west and an occasional local sea (short waves) from either the north (red) or south (green). Limits of the direction estimates are evident by the noise in the color contour plot. These limits are present at low frequencies when there is a lack of wave energy; high frequencies are limited by the depth and mild wave energy.

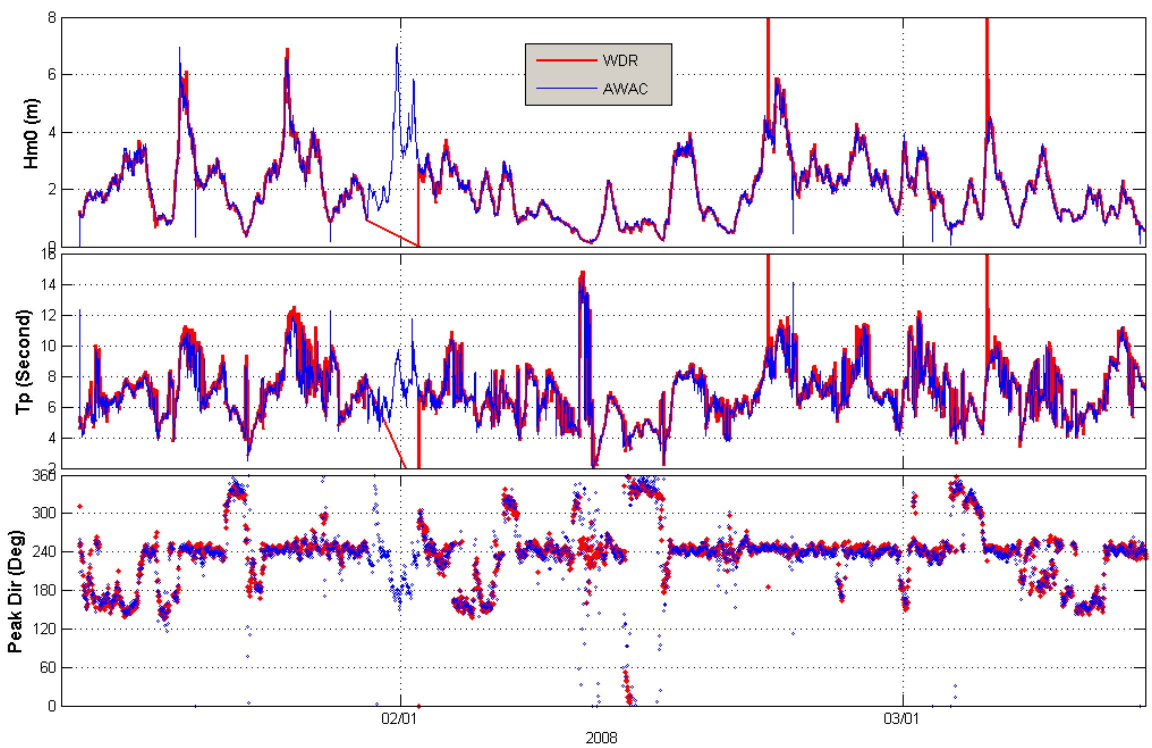

Figure 7. Wave estimates for the AWAC (blue) and Waverider (WDR - red). (a) Significant wave height, (b) Peak direction, (c) and peak direction.

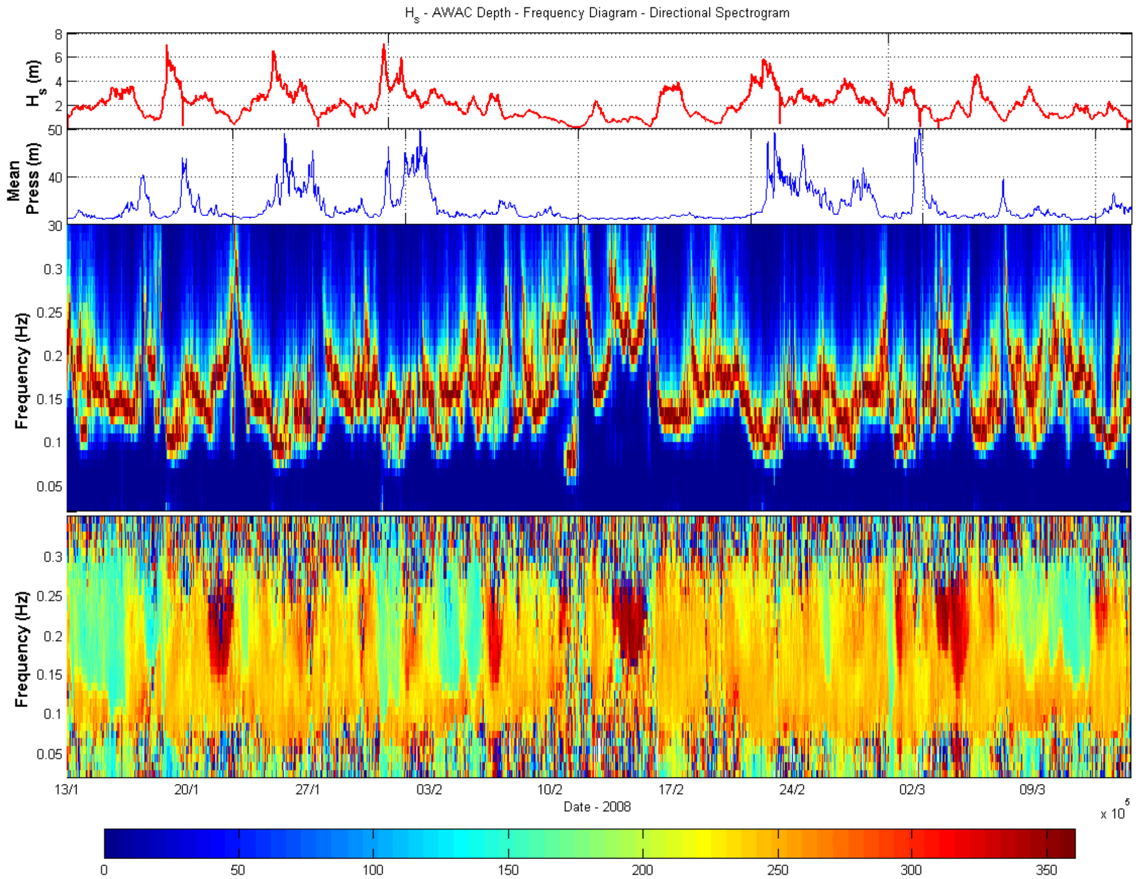

Figure 8. Summary plot of wave measurements, Lysekil. (a) Significant wave height, (b) AWAC depth, (c) Frequency diagram, (d) directional spectrogram.

Concluding Remarks:

Array methods for directional wave measurements from subsurface buoys have been precluded in the past by the fact that the traditional *array* method does not permit buoy motion, namely rotation. Therefore site surveys for wave and currents in waters greater than 60 meters have been performed by using a combination of instrumentation (wave buoys and separate ADCPs). This results in greater cost contributed by the costs of multiple instrumentation, moorings, and additional ship time. This limitation is resolved using the AWAC and the patented SUV measurement method, which does not use array methods.

For Engineers and scientist alike, this is a great advantage since now measurements of waves and currents can be done from a single mooring installation. It also means there is greater security of the measuring equipment since it remains at depth and away from the risks that occur at the sea surface.

During the period of 2005-2008 there have been a series of tests with independent and trusted reference instruments to confirm that the method not only works, but works well. The comparison tests have been long term (multiple months) which has allowed for the exposure of a full range of sea states which ranged from tropical storms to near calm.

Much has been learned through the course of the testing. We now know that care must be taken when designing the mooring so that the mooring's characteristic response does not fall in the wave band of interest. A properly designed mooring, such as the one at Lysekil demonstrates that this can be done with success.

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