Telemetering Environmental Monitoring Buoy and Mooring

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Abstract — A buoy/mooring designed to measure waves with a surface-following buoy was instrumented with an ADCP and water property sensors. Compliant elastic elements at the top of the mooring allow the buoy to move freely with the waves without having to accelerate the mooring and heavy instrumentation. About 710 N (160 lbf.) of midwater flotation at the bottom of the elastic elements help keep the lower part of the mooring taut. The elastic elements provided about 1.3 kN (300 lbf.) of mooring pretension, and, depending on the horizontal current and the wave activity, the tension at the buoy could rise to about 3.5 kN (800 lbf.). Computer modeling of the mooring showed no vertical and minimal horizontal motion in the lower part of the mooring and reasonable tensions that would allow the buoy to follow the waves. Data from the accelerometer in the buoy (telemetered to shore in real-time), the SeaCats in-line and ADCP near the bottom were of high quality. The mooring was recovered by releasing a float from mid-depth that brought a line to the surface from below the elastic elements to allow the mooring (with sensors) and anchor to be retrieved. Validation of the accelerometer wave observations with a near-surface moored Waves ADCP showed good agreement and indicates that the Waves ADCP technology may be used for deeper water waves observations from subsurface moorings.

I. INTRODUCTION

As part of an Open Ocean Aquaculture development effort in New Hampshire, monitoring of the wave forcing of a fish cage and its mooring was desired [1, 2]. Therefore, a simple wave-measuring buoy was constructed from a WHOI telemetry buoy [3] and moored with compliant elastic elements [4]. The elastics allow the buoy to move freely with the waves and to be a good wave follower [1] by not having to accelerate the mooring and sensors mounted on it. During the first year, a single elastic tether element moored the buoy. The vertical component of a strapdown (fixed to the buoy) accelerometer was integrated twice to estimate the vertical wave displacement and therefore the forcing on a nearby fish cage and mooring. The data (20 minute bursts at 10 Hz every three hours) was stored in the buoy on compact flash media and telemetered to shore (~5 miles distant) via spread spectrum radio. On shore the data was processed, and standard wave statistics (significant wave height and dominant wave period) were calculated, and e-mailed to program personnel to use in engineering studies, environmental monitoring, and operational decision-making.

During the second year deployment, additional elastic tethers were used to make the mooring stiffer and sensors were added to provide basic environmental monitoring of the site. An RD Instruments 300 kHz ADCP provided current profiles, Sea Bird Electronics Microcats and SeaCats provided temperature and salinity time series at the top, mid-depth and bottom, with additional Sea point fluorometer and optical backscattering, and Sea Bird oxygen observations being made at mid-depth. The accelerometer sampling program was changed to make 20 minute bursts at 5 Hz every hour, saving all three axes but telemetering only the vertical component to shore every hour.

The telemetry link (DataLinc 900 MHz spread spectrum radios) has worked well, although not perfectly. Telemetry from nearby, larger buoys has been quite good, but some data is dropped each day from the smaller, lighter wave-measuring buoy. (This may be due to greater movement of the wave-measuring buoy due to the wave field.) The transmission path is about 9 km line-of-site to the shore station, whose location was somewhat restricted. Several antennas on a short mast may also contribute to data loss. Future telemetry improvements include higher mounting of directional antennas so that the path is not entirely horizontal in the marine boundary layer.

The second year mooring configuration (Fig. 1) shows the basic arrangement of components. The buoy at the surface has a MicroCat attached to its base for surface water property observations. A second SeaCat was placed between two sets of compliant elastics. This configuration was selected because several good 10 m elastics were available from another completed project, and some could be cut in half and terminated for the bottom component and used whole in the upper. This combined length gave the required amount of compliance to allow the buoy to follow the vertical excursions due to the tides and surface waves and move with the currents observed at the site. Also, it allowed the mid-water SeaCat to be located at 22 meters depth – about the depth of the nearby fish cage and mussel long-lines, thus providing information to the operations and biological components of the program.

The ADCP was moored at the bottom in an upward-looking configuration to minimize motion effects on the data. On the ADCP mounting frame, deep water property observations were made with a SeaCat. The ADCP was set

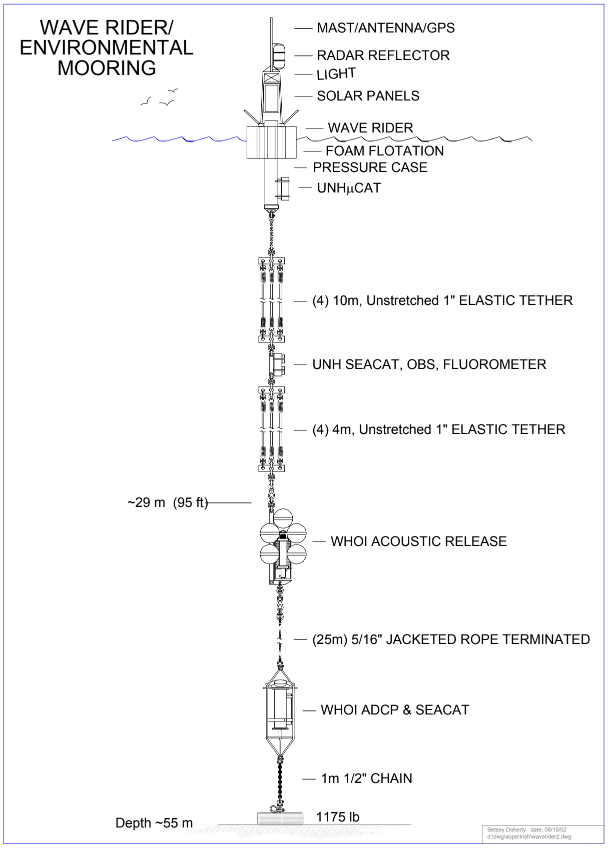

Fig. 1. Monitoring mooring - second year configuration. The wave buoy with telemetry provides flotation, the ADCP at the bottom currents, and SeaCats or MicroCats at the top, middle, and bottom of the water column provide water property observations.

to sample 2-meter bins from near the bottom to near the surface making hourly averages to measure the currents forcing the fish cage and mooring. The SeaCats and MicroCats sampled 4 times each hour.

II. MODELING

To help understand the behavior of the environmental monitoring mooring to current and wave forcing, the WHOI Cable modeling program [5, 6] was utilized. This helped design the best mooring configuration to: (1) allow the buoy to be a good surface follower, (2) keep the buoy in an upright orientation (minimal tilting effects on the acceleration observations), (3) minimize the movement in the lower part of the mooring, and (4) minimize the shock loading in the mooring, allowing lighter-weight, lower-cost mooring components to be utilized.

Based on the first year environmental observations at the site [7], the maximum observed hourly averaged currents were 0.5 m/s, and the maximum waves were ~9 m significant wave height at 10-second period [2]. To model a worst-case scenario, 1 m/s currents and 9-m, 10 second random waves were used to force the mooring configuration. For the static (no waves) tension versus depth case (Fig. 2), the tension at

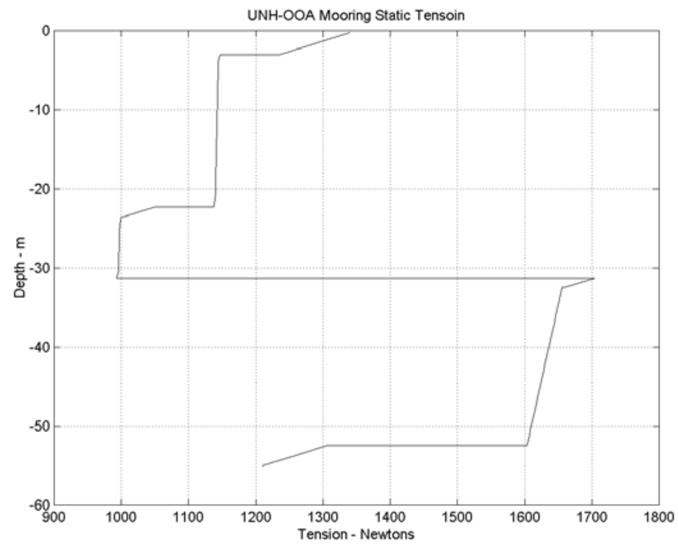

Fig. 2. Static tension versus depth in the mooring.

the bottom starts at 1.2 kN (270 lbf.) and increases with a short chain to the ADCP. At the top of the ADCP (mounted in an in-line frame with a SeaCat and auxiliary battery pack), the tension is up to 1.6 kN (360 lbf.). The 333 N (75 lbf.) increase above the chain is due to the weight of the ADCP package. The wire (or fiber) rope then runs up to the release system (with flotation of about 710 N (160 lbf.)) increasing the tension below the release system to its maximum of 1.7 kN (380 lbf.). Above the release system, the tension drops to just below 1 kN (225 lbf.).

Between the release system and buoy are 4-meter and 10-meter elastic tether arrays. Each tether array is made of four elastic elements that are attached to a circular bridle to distribute the load. Between the two tether assemblies is a SeaCat with fluorometer, optical backscattering sensors (and most recently oxygen). These tethers are stretched from their 14 m unstretched length to about 25 m with no waves and currents, and stretch to over three times their initial length with waves and currents.

The tension in the mooring increases about 150 N (34 lbf.) due to the weight of the SeaCat, sensors and mounting bar. At the top of the mooring, a 1 m length of chain connects the tethers to the buoy with a downward tension of about 1.34 kN (300 lbf.). This downward tension is always positive (see Fig. 7 discussion below), and helps keeps the buoy upright.

With only the 1 m/s current forcing the mooring, the horizontal displacement of the buoy is about 12 m (Fig. 3). For the dynamic simulation, the model run was for 120 seconds, with a time step of 0.1 seconds starting with the static solution. The results were saved and plotted every second for the 120 seconds. With both the waves and currents forcing, the waves move the buoy further horizontally, tilting the mooring and producing the family of displacement curves shown in Fig. 4. The curves to the right were obtained later in the 120 second run, and those at the

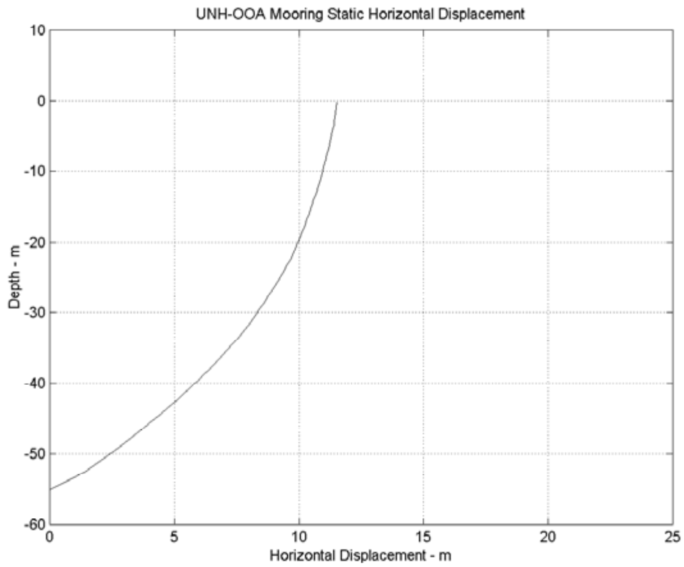

Fig. 3. Static horizontal displacement with depth for 1 m/s currents.

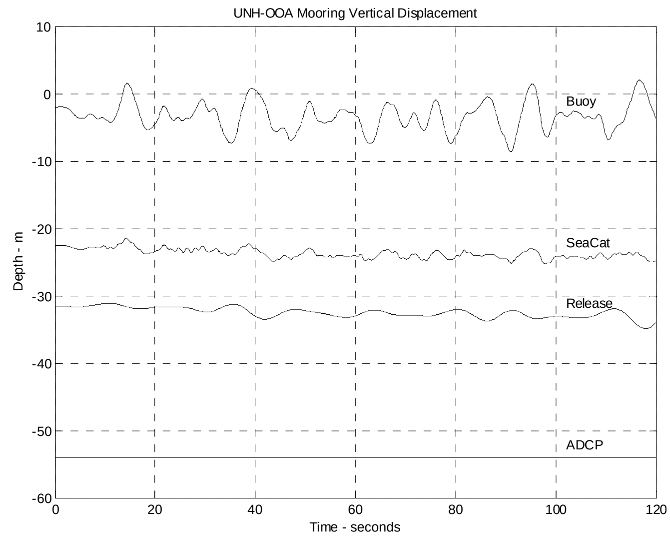

Fig. 5. Vertical displacement time series. The buoy (top) is the same as the waves, then the mid-depth SeaCat, release package, and ADCP.

left were obtained nearer the start. A 20 second "spinup" time was allotted, and probably should have been increased to greater than 40 seconds.

The top of each curve in Fig. 4 ends at the buoy showing its horizontal and vertical position. The vertical displacement time series of four different points on the mooring is shown in Fig. 5. The vertical displacement of the anchor (not shown) is negligible as the program fixes it to the bottom. The program also forces the buoy to follow the wave surface (top line in Fig. 5). The bottom line, Fig. 5, is the ADCP vertical displacement, and it does not significantly move up and down (as it would if were attached to the buoy), but does tilt with the waves as shown in Figs. 3 and 4. The bottom of the mooring has the most tilt, and this is the main problem with making ADCP observations from the bottom of a surface mooring. A typical record of ADCP tilts (Fig. 6) shows that the tilts are less than those from the model predictions, but the forcing was also less. The observed maximum currents during the storm about year day zero reached a maximum of about 0.25 m/s (stronger currents were deeper), with 3 m significant wave height, 7-second waves. The higher frequency oscillations on the lower, weather-forced oscillations are tidal. The observed tilts are as

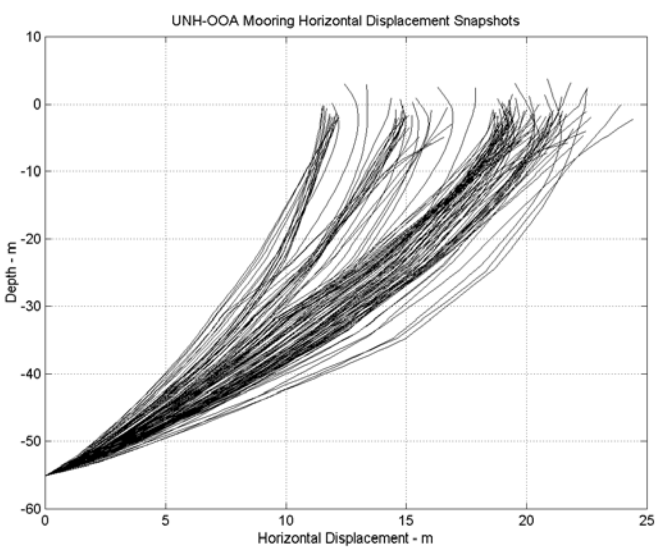

Fig. 4. Horizontal displacement time series of the mooring with 1 m/s currents and 9-m significant wave height, 10 second wave forcing. The curves are 1 second apart from a 120 second long model run.

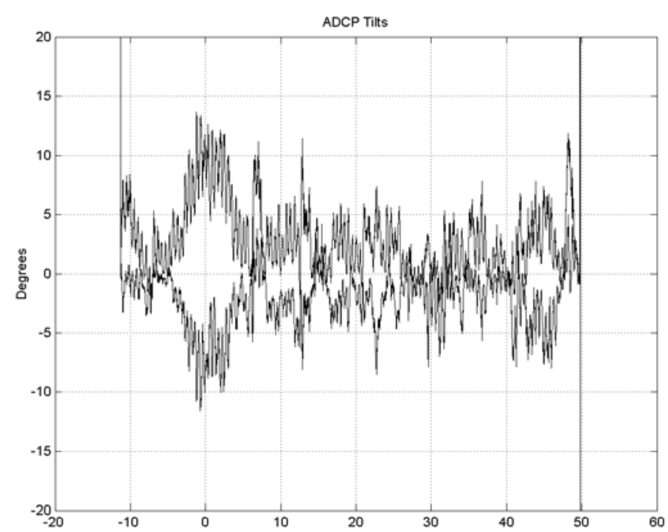

Fig. 6. Typical tilt and roll of the ADCP during a large storm around Year Day zero indicates a maximum tilt larger than desired. The maximum current speed was about 0.25 m/s, and waves were 3 meters high.

large as the ADCP can handle, and larger tilts would probably degrade the data. The standard deviation of the tilts is 0 to 1º, showing that wave effects on the tilt of the ADCP at the bottom of the mooring are greatly reduced by the compliance of the elastic elements.

The middle two curves (Fig. 5) are the SeaCat and release vertical displacement. The release has little motion except low frequency tilting of the mooring. The SeaCat shows more high frequency oscillations as it is between the two tethers. Note the phase difference of the release movement from the surface. The release is seeing tilting since the mooring cable prevents any significant vertical motion.

The tension time series at the top and bottom of the mooring (Fig. 7) show typical expected loads. The tension at the bottom is lower in magnitude and generally in phase with the surface forcing (with some phase shifting at different times due to the dynamic behavior of the compliance in the top of the mooring). The trend toward increasing tension with time is due to the waves causing larger horizontal displacement with time. The minimum tension is always greater than 2.2 kN (500 lbf.), and less than 3.5 kN (800 lbf.). With the elastic tethers it is important that the tension in the tethers never goes slack, and with no current and maximum waves, the model predicts that the tension will decrease to less than 450 N (100 lbf), but does not go to zero.

With the maximum expected tension at the buoy less than 3.5 kN (800 lbf.), the 5.4 kN (1,200 lbf.) buoyancy of the buoy system had enough reserve so that the buoy would be a good wave follower. The tension in the mooring showed no excessive shock loading, and standard 5/8" mooring hardware and 5/16" jacketed wire rope were more than adequate to provide a safe mooring.

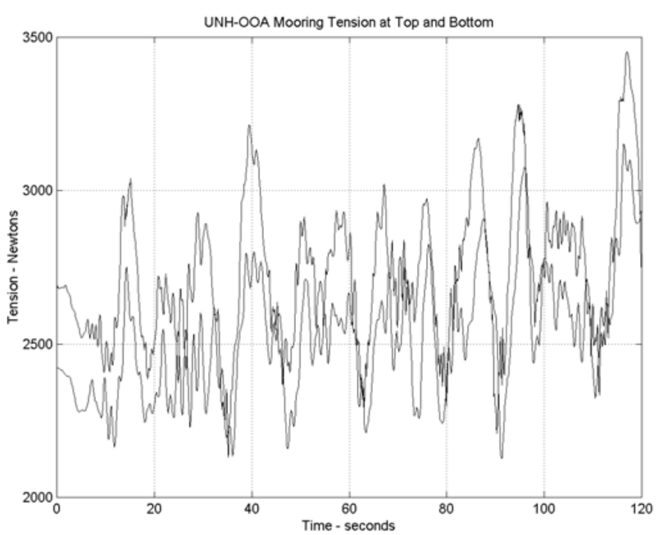

Fig. 7. Tension time series at the top (higher tension line) and bottom (lower tension line) of the mooring with maximum current and wave forcing.

III. DEPLOYMENT AND RESULTS

A. Deployment and Recovery

The mooring was deployed buoy-first and anchor-last from the 50-foot R/V *Gulf Challenger,* as we would deploy a standard chain catenary mooring. Before deployment, the mooring was fully assembled and laid out on the deck (Fig. 8). The buoy was picked up and set in water with the A-frame and trawl winch, and the components then deployed by hand over the stern down to the anchor (Fig. 9). The A-frame lifted the anchor on a quick release and set it in the water.
The mooring was then towed into position and the anchor released. The mooring generally settled out with the anchor about 1/3 the distance back toward the buoy from the release point. When deployed, the buoy was riding stiffly, and nearly vertical (Fig. 10).

Because the elastic tethers are at the top of the mooring, normal recovery, by picking up the buoy and pulling in the mooring, cannot be done. Also, environmental regulations for this site prohibited leaving the anchor behind each deployment. As the ADCP was at the bottom, care must be taken not to lose this instrument (and data) should the buoy break free at the tethers. The subsurface release package accomplishes this by: (1) providing flotation for the lower instrumentation (to prevent damage by hitting the anchor and being dragged around by currents), and (2) releasing a float that brings a line to the surface so the release system and lower part of the mooring can be recovered.

The recovery line is connected to the wire (or fiber rope) mooring line below the release package. The ship recovers the float and pulls up the line to recover the release system, disconnects the upper part of the mooring with buoy, and leaves it in the water while recovering the wire (or fiber

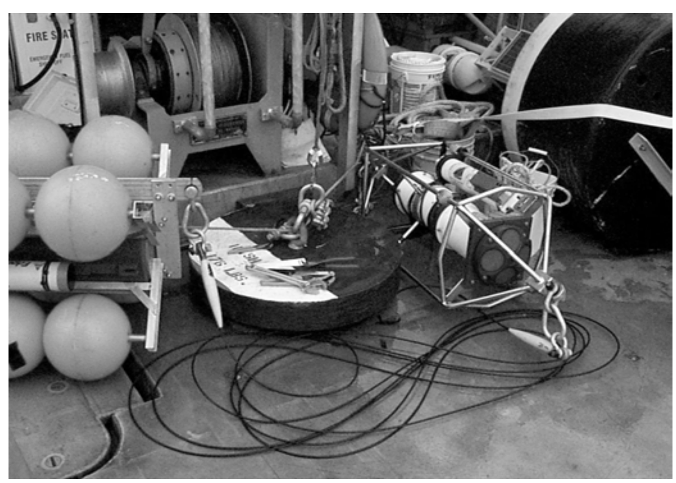

Fig. 8. The buoy far right, the ADCP next with SeaCat and auxiliary battery pack in an in-line frame, the 2,500 kg (1,100 lb.) anchor is in the center and the release with float system on left. The EdgeTech acoustic release is the cylinder between the flotation balls. The 5/16" wire rope from the ADCP to the release float is seen faked out in front of the anchor.

Fig. 9. The buoy has just been launched, and the elastic tethers are being paid out over the stern by hand. The remaining components are deployed over the stern by hand down to the anchor.

rope) mooring line, ADCP, and anchor. Then the wave measuring buoy, SeaCats, and elastic tethers are recovered. The EdgeTech AM200 releases have proven an adequate (although not perfect) solution with one out of eight release attempts (at 3-month intervals) failing. There were also problems when the released line or float caught on some component of the mooring and did not surface. The backup recovery is a diver snapping a line to a pear ring below the release assembly and then pulling the bottom part of the mooring to the surface and recovering as if it had released.

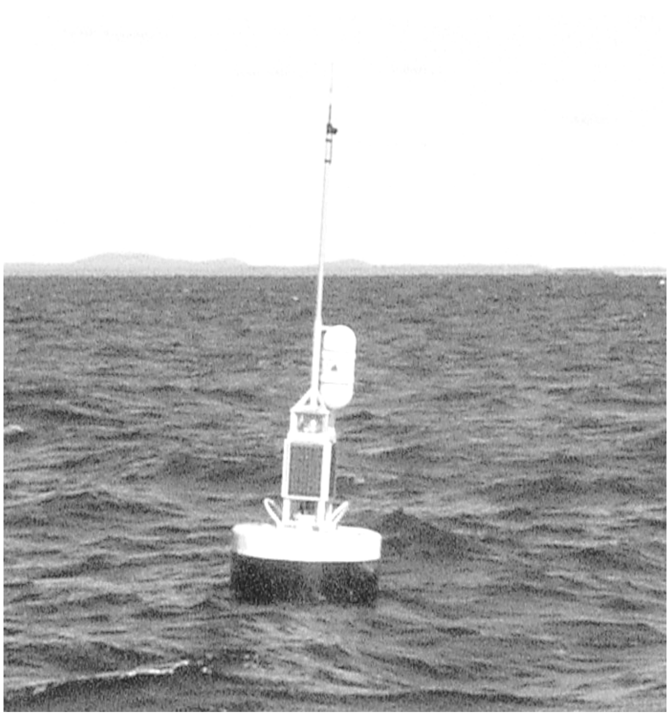

Fig. 10. The buoy in position after deployment. The solar panels charge the data system batteries, the white radar reflector, telemetry antenna with GPS are seen above the foam flotation collar. The top of the 6" diameter pressure tube can be seen in the center of the buoy.

B. Results

The static condition with about 1.3 kN (300 lbf.) tension was about what was observed when the mooring was first deployed (the amount of foam submerged). During the first year's deployment with only one elastic tether (and no environmental instrumentation other than waves), the buoy was observed to significantly pitch and roll with the waves. The accelerometer in the buoy was fixed to the buoy, so that any pitch and roll movement of the buoy would couple the acceleration of gravity variations due to pitch and roll into variations in the "vertical component" of acceleration as seen in the buoy coordinates, and produces an increased instrumental noise background against which the surface waves must be measured. Therefore, reducing this effect was important. During the second year, with four elastic tethers the mooring had a higher tension and this pitching movement was greatly reduced. The stiffer mooring did improve the wave measurements and reduce this noise.

The water properties were measured with two SeaCats (at 22 m and 53 m depths) and a MicroCat at 1 m. The data from these sensors is little affected by the motion of the mooring, other than to flush the sensors. The SeaCat at 22 m also had a fluorometer and transmissometer. The limiting factor in the mooring deployment length is caused by biofouling on these sensors and led to a 3-month turnaround. However, in late summer, this time may be too short between turnarounds. The temperature sensors are accurate to within a couple of millidegrees per year, but the conductivity does tend to drift toward lower values with biofouling, which is reduced by the use of "poison plugs." The optical sensors are more severely affected by biofouling. The data gathered by these sensors appear to be of good quality and provide information for monitoring environmental conditions near the aquaculture operation. The real-time telemetry of wave data and surface water temperature and salinity is providing hourly data to the operational and other interested persons in the program.

The first year's current observations were made with the ADCP at the top of the mooring moving with the buoy, although not fixed to the buoy [7]. The wave measuring mooring made current observations with the ADCP at the bottom. Both moorings were within 0.5 km in the same location but since the moorings were not deployed at the same time, an evaluation of the mooring configuration effects on the current observations can only be made by comparing the results of tidal analyses of the records. The data were averaged to hourly values and a harmonic tidal analysis [8, 9] done. The tidal constituents are the same within the statistical uncertainty of the analysis [10]. This leads to the interesting conclusion that for the lower frequency signals (e.g., tidal and weather forced) the randomness of the waves does average out and the lower frequency variations are resolved properly.

C. Wave Measurement Validation

To validate these wave measurements with a strapdown accelerometer and provide a more complete understanding of the elastic mooring behavior, comparisons are being made with a moored RD Instruments Waves ADCP mounted on a midwater, subsurface float [11]. The advantage of comparing results with the Waves ADCP is that it estimates the wave spectra and statistics by three independent methods (pressure, surface elevation, and near surface velocity). This redundancy was important because in 55 m of water, the 600 kHz ADCP could not be deployed on the bottom and reliably sample the waves, and we wanted to test the methodology of measuring waves with an ADCP from a subsurface mooring (Fig. 11). A consistency among the three independent methods would indicate that the data were good and could then be compared with the accelerometer buoy observations.

The first deployment included a storm with 5 m significant height waves as well as relatively calm periods (Fig. 12), providing a variety of conditions to compare results. The three ADCP spectra and the integrated accelerometer spectrum from the peak of the storm (0100 UTC 17 October 2002) are in good agreement (Fig. 13). Other spectra from relative calm periods are also in good agreement. This indicates that both techniques are working well.

Of the three ADCP spectra at the wave peak (Fig. 13), the pressure is the highest, the velocity next, and the surface track lowest. Because the bin size on the ADCP was set to 1 m, the error in the surface estimate is larger, and these results should probably be ignored. The wave results from the near surface velocity might be reduced somewhat if the subsurface float (and ADCP) were moving with the waves due to drag.

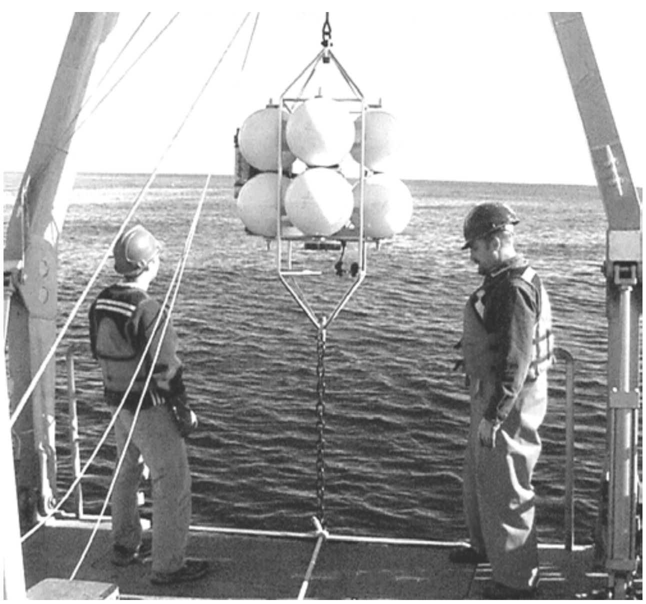

Fig. 11. Recovering Waves ADCP in buoyant frame subsurface moored configuration (10 m deep in 55 m of water). The ADCP is behind the flotation spheres in the middle of the frame and barely sticks out above and below the floats.

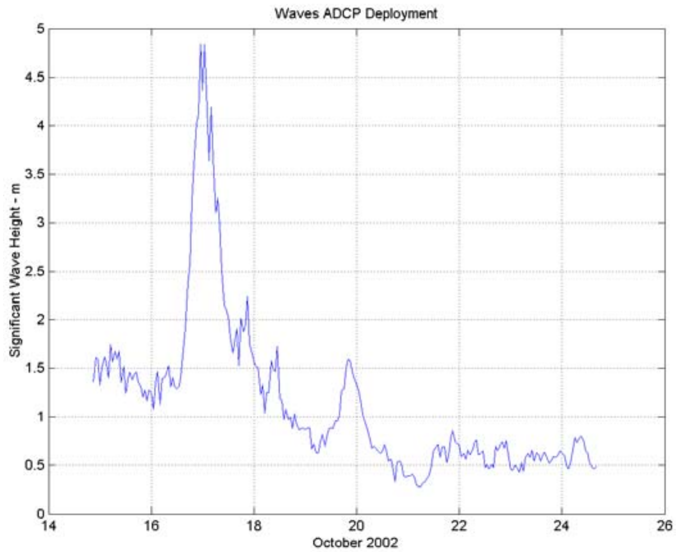

Fig. 12. Significant Wave Height time series estimated from the Waves ADCP velocity data showing the storm peak at 0100 UTC 17 October 2002.

Therefore, one might expect these results to be slightly lower, as observed. The accelerometer results show a slightly broader wave peak and slightly higher amplitudes than the ADCP, but not significantly. That the three ADCP and the buoy accelerometer estimates appear consistent, indicates that (1) the wave buoy observations and estimates of wave height are good, (2) that the Waves ADCP can make good observations of surface waves when mounted on a stiff, mid-water mooring, and (3) that the differences in the curves (Fig. 13) indicate that the noise limitations in both instruments need to be properly considered to get good wave statistics.

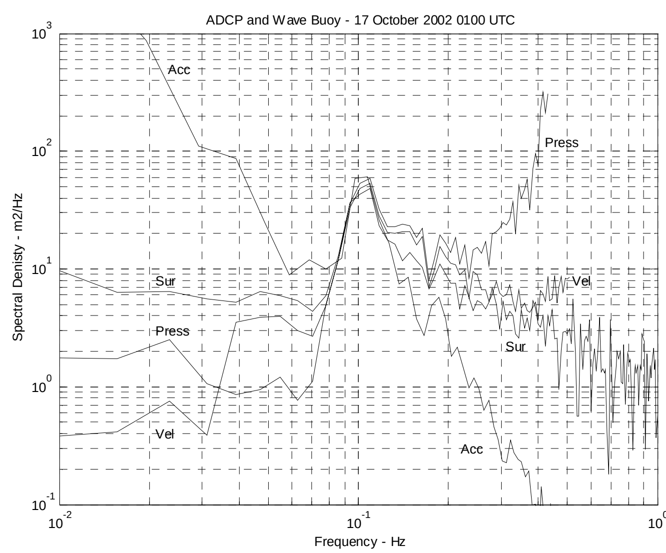

Fig. 13. Wave spectra for the peak storm from the Waves ADCP and the wave buoy for 0100 UTC 17 Oct 2002. The wave-measuring buoy accelerometer is Acc, the ADCP pressure is Press, the ADCP velocity is Vel and the ADCP surface track is Sur.

The noise level in the four methods of estimating the waves can be easily seen where the curves do not fall on top of one another. This shows over what frequency band the variance of the spectra can be integrated to provide estimates of significant wave height. Including low frequency noise from the accelerometer, or high frequency noise from the ADCP, will bias the estimates toward higher significant wave height. No one method appears to resolve the waves best, with the accelerometer being best at higher frequencies and the ADCP best at lower frequencies.

D. Conclusions and Future Directions:

A mooring for measuring waves, current profiles, and environmental parameters was designed and constructed to allow the buoy to move with the waves and measure waves optimally, while providing a low motion mooring for current and water property observations. The mooring was deployed twice in 2001 (accelerometer only), three deployments of 3, 3, and 4 months each in 2002, and with three deployments of 1 month, 3 months and 3 months (so far) in 2003, and has performed well during that time. Further testing/comparisons are being conducted with the Waves ADCP to understand those observations being made from a subsurface mooring, as well as with the accelerometer wave measurements from the elastically moored buoy.

To be an effective observatory, the buoy/mooring also needs to telemeter the data to shore in near real-time. This is successfully being done via Spread Spectrum radio with data collected on the surface buoy (acceleration), but the subsurface sensors below the tethers were not connected with the buoy. As a test of a hard-wired conducting link around the tethers, a prototype coilcord electrical conductor (around one elastic tether) [12] will be deployed in the fall of 2003 to bring the signals to the buoy from mid-water sensors. Then the mid-water (and maybe the bottom SeaCat and ADCP) data can be sent to the surface buoy and radioed to shore hourly and served on the WWW. An alternative would be an acoustic telemetry link around the tethers, but then power could not be supplied to the underwater sensors. With power supplied by the buoy and data recorded in the buoy, the subsurface sensors could be simplified (lower cost, but with no redundancy in power and data recording). Plans are for continued deployment, with additional sensors as appropriate, for the next few years.

ACKNOWLEGEMENTS

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