Observatory Measurements of Waves and Current

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Abstract - Real time observations of waves and current at the Martha's Vineyard Coastal Observatory (MVCO) from bottom mounted MAVS current meters permit critical events to be captured for subsequent analysis. Storm waves associated with winter northeasters and tidal and wind-driven current generate bottom stress that may fluidize the bottom. Vector velocity and pressure measurements will be made 75 cm above the bottom at two locations, at 12-meter depth and at 15-meter depth 2-km farther offshore. Power for these instruments will be supplied from nodes in the MVCO network and data from each instrument will be transmitted to the node for forwarding to shore on the network over an optical fiber. The benefit of the observatory to our ability to capture critical events is the power for continuous high-speed sampling and the capacity of onshore based loggers for storing data for indefinite deployment. Critical storm events will be selected for analysis, as in autonomous deployments, but continuous sampling and logging over extended periods give us more opportunities to distinguish conditions that affect the sediment and attenuate waves.

I. INTRODUCTION

Real time connectivity to an observatory node is a scientific benefit but a technological challenge. The benefit is continuous monitoring without practical limitations on electrical energy or data volume. Immediacy is a critical benefit for warning systems and operational information. Synchronization of related but independent measurements is facilitated by real time data return. But many if not most applications can be satisfied by pseudo real-time data return. In this case, data may be acquired continuously but stored and forwarded in blocks, thus being delayed by at least the length of the block, which is typically 20 minutes.

With this kind of application in mind, the Martha's Vineyard Coastal Observatory (MVCO) was started in 1999 [1] with a shore station at the Katama Air Park in Edgartown, MA. Cable from the shore station to the beach was laid in a trench, passed through conduit to a point offshore, and then laid to a node at 12 meters depth. The conduit under the beach was installed by directional drilling and the cable was laid and buried from that point to the 12-meter node. A node was also established on the beach for a meteorological mast. Data from meteorological sensors on the mast and from oceanographic sensors at the 12-meter node have been served at the MVCO web site [2] since May 7, 2001. As part of the Coupled Boundary Layer Air-Sea Transport study (CBLAST), a tower was installed in 15-meters depth 2-km seaward of the 12-meter node. This was provided with a third node and a cable was laid connecting the Air-Sea Interaction Tower (ASIT) to the 12-meter node in October 2002.

In this paper, structure of the observatory and some of the permanent software is discussed. Examples illustrate how data from a continuously sampling sensor are logged. Software recovers these logged data in the science lab over the Internet and this is illustrated. These examples serve as a rough guide as to how one might piece together the existing systems that are required to measure waves and current at the observatory. Hardware that will be used is described and a demonstration of web based current measurements from the Modular Acoustic Velocity Sensor (MAVS) [3] is presented. As of this writing, the systems that are required for measuring waves and current have been developed, tested, and are ready for field deployment within the next few weeks.

II. OBSERVATORY NETWORK

A. Cable

Single mode optical fibers loosely contained in a gel-filled stainless steel tube form the center of the cables that are the spine of the observatory. Ten fibers are contained in the cable leading from the shore station to the 12-meter node where two are used and the remaining eight are available for extension cables. Four fibers are contained in the cable between the 12-meter node and the ASIT node where two are used and a third is available for direct connection to sensors exceeding the bandwidth offered by the node. The fourth fiber is held in reserve as a spare.

Electrical power transmission occupies most of the bulk of the cable. Three power circuits, six #13 wires with 60 Hz, 1500 vac, bring power from the shore station to the 12-meter node. There the voltage is stepped down to 240 vac in a transformer box sealed to the end of the cable. Underwater pluggable connectors on the oil-filled and pressure-compensated transformer box allow the node to be disconnected from the transformer and brought to the surface for servicing without disturbing the transformer and the other cable or cables connected to it. The transformer box is where the optical fibers are terminated on underwater pluggable bulkhead connectors [4].

The cable between the 12-meter node and the ASIT node also has transformers at each end. Voltage is stepped up from 240 vac to 560 vac at the 12-meter node end and stepped back down to 240 vac at the ASIT node end. This minimizes the power transmission loss on the 2-km length of four #12 conductors in the cable. The oil-submerged transformers are rated for 2 KVA. Extra fused (5 amp) 240 vac sockets are provided at the ASIT end for heavy drain instrumentation. The two optical fibers for the node and the third fiber for dedicated connection to a high bandwidth sensor are brought out from the transformer box on pigtails.

A ground fault detector circuit is carried from the shore station, through the 240-v underwater pluggable connection between the first and second cable to the ASIT node. Three conditions can trigger a ground fault interrupt: current imbalance in the 1500 vac line to the 12-meter node, current from the 480 vac circuit of the second cable to ground, and voltage on the neutral wire of the 240 vac output at the ASIT transformer box. Water leakage in the 12-meter node transformer box is detected by an array of leak detector sensors and conveyed through the power connector to the ASIT node where a leak condition can be monitored. The ground fault and water leak signals are carried in four additional wires in these two cables. The ground fault is part of the 240-v underwater pluggable connector at the 12-meter node end and the water leak signals are part of the 240-v power connector at the ASIT node. Each cable is double steel jacketed (torque balanced) and covered with a polyethylene jacket.

The cable from the shore station to the 12-meter node was buried with a hydro-jet insertion tool to a depth of 1.5 to 2 meters below the bottom. Observation of cables around the 12-meter node convinced us that wave action on the bottom fluidized the sand episodically and caused heavy cables to bury themselves. Therefore the second cable was weighted with 2.5-cm (1") bright steel wire rope (3.4 kg/m submerged weight) to which it was lashed and laid on the bottom for passive burial.

B. Nodes

The end of each cable has a node where power is distributed and Guest Ports enable data entry. The first node to become operational was at the meteorological mast with 10 Guest Ports. Next was the 12-meter node with 15 Guest Ports. At the ASIT node, there are 19 Guest Ports of which 15 can support RS-232 or RS-422 serial communications. All of the Guest Ports can support Ethernet communications. Each node contains a Cisco 2511 router and a Cisco 3500 switch to connect the Guest Ports to the optical fiber driver and receiver.

A Guest Port is programmed for power, communications, and fault override. Commands are addressed to specific Guest Ports from the network. For example, a conversation to set up Guest Port 01 for 24-volt power, RS-232 Tx/Rx data format, and data fault override is shown in Fig. 1.

Commands S request status, B control 24-volt power, D control data type, and O select fault override mode. Each command has a response mirroring the command except status. Responses of status indicate port number (S01), voltage, current, and ground current for supply A, voltage, current, and ground current for supply B, water leak, internal temperature, four additional ground fault readings, and last, two flag registers. The first flag register is a binary encoding of Hi-Voltage on, auto GFD enabled, auto GFD fault override, data fault override, data fault, and three bits to represent data type. The second flag register is a binary encoding of overcurrent B, overcurrent A, auto ground fault B hi, auto ground fault B lo, auto ground fault A hi, auto ground fault A lo, supply B on, and supply A on. The example given shows a final status response for a port correctly configured for powering and forwarding MAVS data as well as permitting commands to be sent to MAVS. This sequence of commands can be sent to the IP address of the node via telnet.

Command	Response
#P01,S	S01,01,00,80,01,01,7F,00,AA,00,00,00,00,08,00
#P01,B,1	B01
#P01,S	S01,02,00,81,01,01,80,00,BF,00,00,00,00,88,00
#P01,D,1	D01
#P01,S	S01,03,00,80,C2,01,80,00,B6,00,00,00,00,81,02
#P01,O,1	O01
#P01,S	S01,03,00,80,C1,02,7F,00,B7,00,00,00,00,91,02

Fig. 1. Command sequence to configure Guest Port 01 for 24-volt power (supply B) on, RS-232 Tx/Rx, and data fault override.

Alternatively, a web-based interface can be used to configure the Guest Port, as shown in Fig. 2. This configuration tool is a PERL script that uses the common gateway interface (cgi-bin). The telnet CPAN module communicates the commands to the Guest Port each time the user presses the "configure port" button.

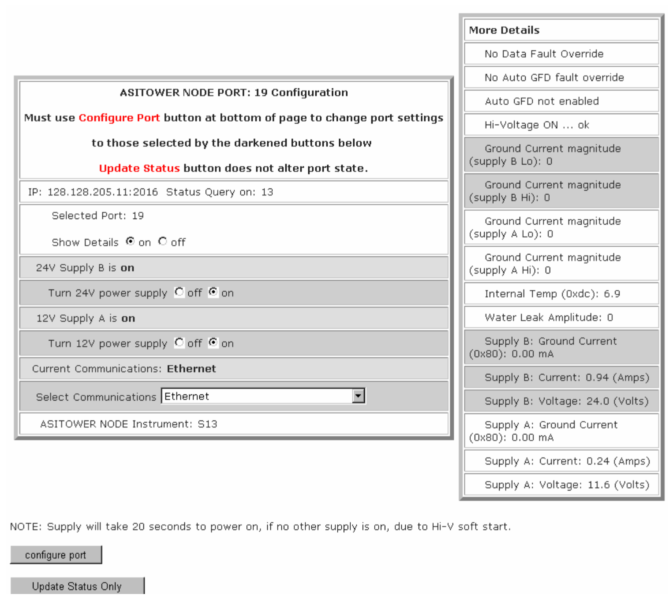

Fig. 2. Web-based configuration tool to set up Guest Port remotely.

Ethernet is supported at each Guest Port and a Cisco 3500 switch accepts the Ethernet outputs of each Guest Port plus the Ethernet output of the Cisco 2511 router as 10/100 Base-T Ethernet [4].

C. Packet Communications

Since MVCO uses single mode, single carrier frequency optical fiber communications between nodes and the shore station, a pair of fibers is required for bi-directional communications. The Cisco 3500 Ethernet switch splits the signals from the optical fiber receiver (GBIC) to the Guest Ports and the Cisco 2511 router in each node. The router and switch also combine the signals from the Guest Ports to the optical fiber transmitter (GBIC). The Ocean Systems Lab of the Woods Hole Oceanographic Institution developed the Guest Port [1].

At the shore station the six optical fibers connect to three sets of transmitters and receivers. A Cisco 2612 Ethernet switch combines these signals for connection to a T1 commercial communications line. Fig. 3 illustrates these elements for the three nodes in place in January 2003. The connection from the router to the switch is shown as 10Mb while the connection to the shore station is 100Mb. The Cisco 2600 router at the shore station connects to the T1 line at 1.4Mb.

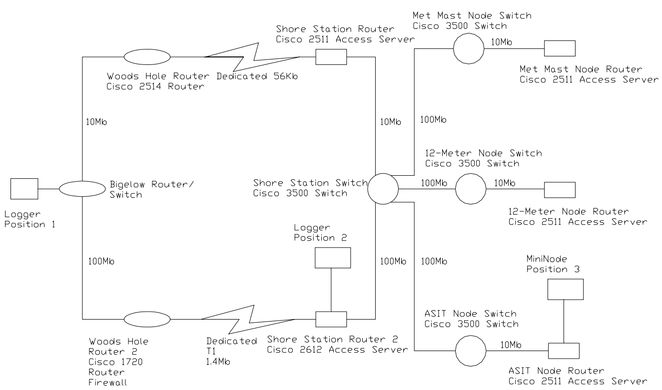

Fig. 3. MVCO Network Configuration, courtesy John Krauspe, Woods Hole Oceanographic Institution.

Standard TCP/IP communications with the Guest Port allow users to directly configure the port and also log data streams. However, at the sensor level, this introduces technological issues. The technological difficulties arise from the discrete message characteristics of data transfer on the Internet. Communication between a sensor and a computer via the Internet, unlike a dedicated line, requires addressing and protocol. Serial/IP (Tactical Software, Nashua, NH) allows access to the serial devices through TCP/IP communications. A logging computer is required to capture data from the sensor.

D. Computer Insertion

There are several places where a logging computer might be inserted in the Internet communications line, shown as positions 1, 2, or 3 in Fig. 3.

1) Scientific Laboratory - At the scientific laboratory end (position 1), a computer could connect to the Internet and open a bi-directional serial communication link to the Guest Port hosting the sensor using telnet, Crosstalk, or other commercial software. If the sensor is transmitting data, the computer can receive and capture it. This mode is easiest to implement and understand. Software must run on the computer to make the presence of the Internet in the link be transparent. A CVI/Lab View (National Instruments, Austin, TX) logger has been developed to open a number of ports that can be logged simultaneously (Fig. 4).

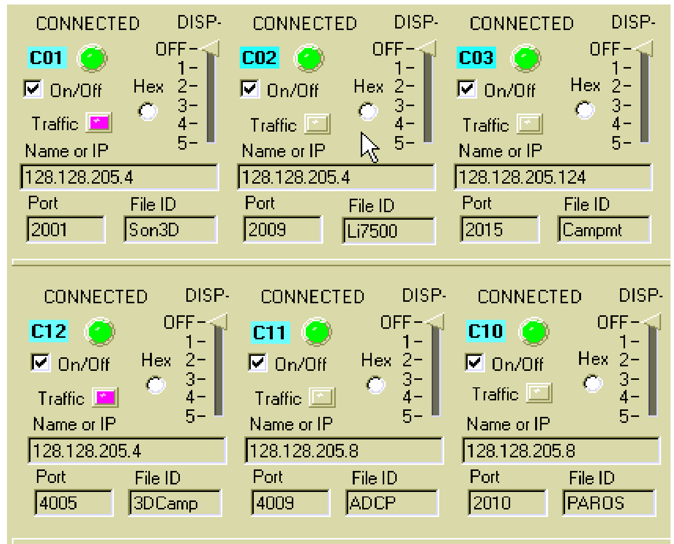

Fig. 4. SPIPTCP1 Lab View screen to enable logging serial data streams in the scientific laboratory or remotely at the shore station.

2) Shore Station - One disadvantage of putting the computer at the scientific laboratory end of the line is loss of data in case of failure of the commercial T1 line and loss of power on the scientific laboratory computer. An automatic 8 kW generator backs up the shore station power with a 4 kW UPS to eliminate power interruptions. So a computer at the shore station is safe from two commercial utility failure modes, the most common failures experienced during storms. This is position 2 in Fig. 3.

Control of a logger at the shore station is similar to that in the scientific lab except that a Virtual Network Computer (VNC) connection is required. The screen is the same as that when the computer is at position 1 (Fig. 4.)

In either position 1 or position 2, control of the sensor is generally required and VNC permits this control as shown in the transaction with MAVS in Fig. 5. The display shows interactive selection of display format as speed and direction without averaging. The last commands sent were two <Returns> to cause MAVS to run. The format of the transmitted records are day of month, time, temperature, pressure, conductivity, pitch, roll, speed, direction, and vertical velocity.

3) MiniNode - There is a third place where a computer can be placed in the line shown in Fig. 3 as position 3.

Placed between the sensor and the Guest Port with an Ethernet connection to the Guest Port, a logging computer prevents loss of data by failure of a commercial utility. A PC 104 logger has been installed at the Air Sea Interaction Tower (ASIT) with 8 serial inputs to support as many as 8 sensors but only monopolizing a single Guest Port. This at once conserves resources and protects against utility failure. This PC 104 computer is called a MiniNode because it is connected to a Guest Port with the Ethernet option but appears to sit directly on the network. Several MiniNodes have been built for use both on the seafloor and on the ASIT.

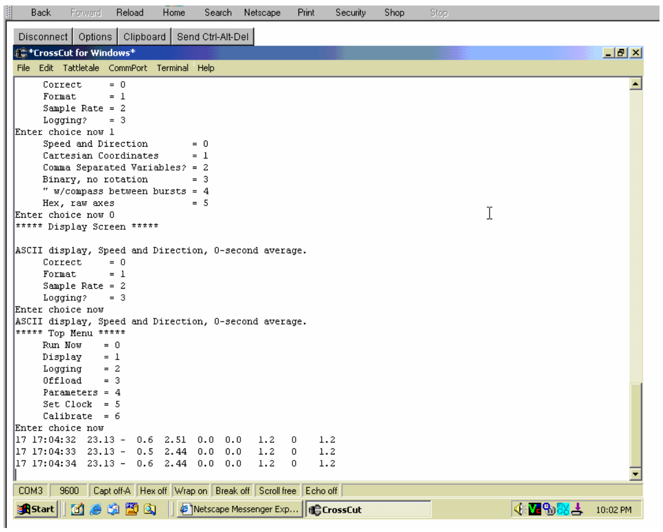

Fig. 5. Transaction between computer in the lab and a MAVS2 current meter on a network mediated with VNC Desktop under Internet Explorer.

The MiniNodes can be accessed by Internet the same way as can the shore station computer: via VNC. Fig. 6 shows a MiniNode configuration screen in which the communication baud rate to each port of the MiniNode is set, the log file label assigned, and the display screen selected. MiniNode software sets a power turn-on delay for each port to prevent surges from causing a power overload during initial charging of sensor power supplies.

4) Offloading of Logged Data - Data can be logged from a sensor at any of the three positions shown in Fig. 3. Logging is set up using VNC from the scientific lab at a computer at the shore station as shown in Fig. 4 or at a MiniNode as shown in Fig. 6.

When 20-minute block data are stored, either at the shore station or on a MiniNode, a copy of the file is placed in a separate ftp accessible directory. A science lab based Linux workstation has been configured to retrieve and, upon successful retrieval, delete these duplicate files. This provides continuous duplicate copies of all data.

Clocks on the remote logger and the Linux workstation are synchronized using external time servers. Automated data retrieval (ncftd) and processing are accomplished using the Linux cron utility.

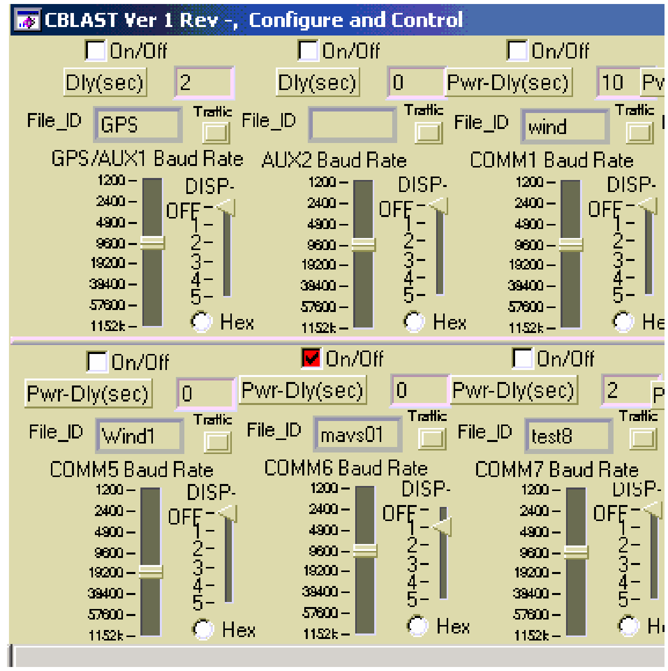

Fig. 6. MiniNode logger configuration screen.

The raw data are archived and Matlab (Math Works, Natick, MA) scripts are used to provide burst-averaged statistics and generate graphics for near real time display using the Apache web server. Fig. 7 shows an example. In this display, pressure measured at the 12-meter node and logged at the shore station was retrieved by a Linux system running a cron job. These data were processed by Matlab and displayed on the MVCO web site as a time series of wave height.

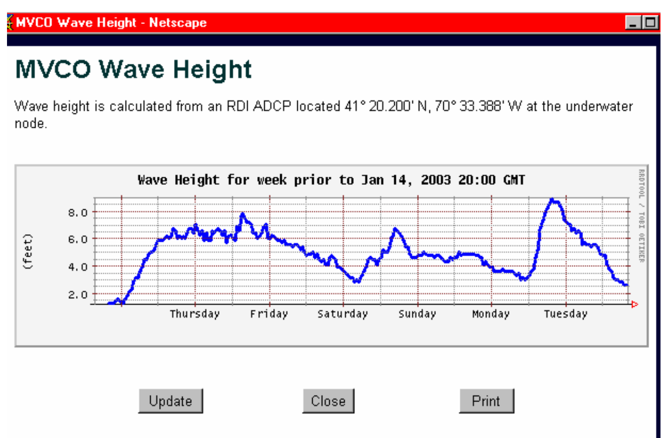

Fig. 7. Processed data from a computer logging files at the shore station.

III. SENSORS

A. Directional Wave Spectra

Attenuation of waves across the continental shelf is important and not well understood. The availability of the MVCO with the recently installed ASIT offers an opportunity to measure wave attenuation between 15 meters and 12 meters depth during major winter storms. The observatory has been the missing link in such a study before now but the extension of the cable to the ASIT on September 14, 2002 and its connection to the node on the ASIT on September 27, 2002 made this attenuation study possible.

The first experiment using the ASIT was SPACE, an acoustics study employing 13 tripods near the ASIT, with cables connected to the ASIT node. This experiment was concluded at the end of November leaving many cables on the bottom near the tower legs. As of the end of December 2002, most but not all these cables have been recovered. When the last cables have been retrieved, a MAVS on a small tripod will be deployed slightly north of the northeast leg (1-m diameter pile) in 15.24-m (50-ft) depth. At this location, the east - west tidal current will not shed pile-induced wake over the sensor. Thirty-six meters of cable to the water surface will permit displacing the tripod 15-m north of the 1-m diameter pile. A 15-m extension cable will complete the connection from the water surface to a Guest Port on the ASIT node at the platform 12 meters above the surface. The cable will be tie-wrapped to a bar welded along the leg.

A second MAVS on a tripod will be deployed at the 12-m node. This node has no surface expression. The tripod will be lowered to the bottom 20 m south of the node and divers will carry the 36-m cable to the node for plugging into a Guest Port. Signal from this second MAVS will be transmitted to the shore station on a separate optical fiber from that of the first MAVS. Both signals will be logged at the shore station.

Fig. 8 shows part of two tripods with MAVS current meters attached ready for deployment at the 12-meter and 15-meter sites. MAVS is visible only on the near tripod. The measurements from these sensors will be processed to obtain directional wave spectra [5, 6].

B. MAVS Web Site Pre-2003

In anticipation of installation of two MAVS instruments at the MVCO, a web site serving two MAVS instruments on the Woods Hole Oceanographic Institution pier was established. A PC 104 computer received serial data from two MAVS instruments under control of a program in Quick Basic. Quick Basic then sent files via ftp to a server for storage and display at baker.whoi.edu (see Figs. 9 and 10). A utility line driven power supply backed up by a battery within the weather tight box on the pier provided power to each instrument but there was no power backup for the PC 104 to capture data during storm induced utility failures. This defect never interfered with data logging during the interval of current sampling because Woods Hole had no hurricane in 2002. Other than that, lessons were learned in establishing this web site. These are documented here to save others similar false steps.

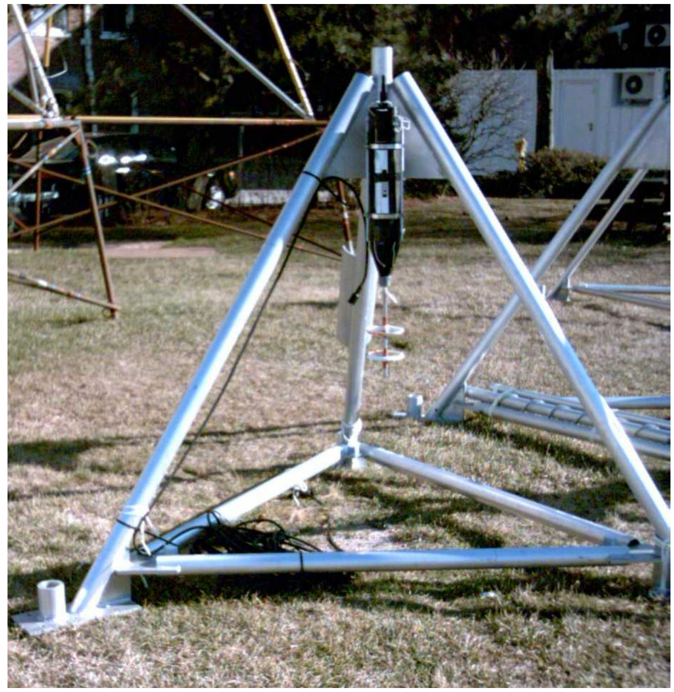

Fig. 8. One of two tripods with MAVS sensor to observe the vector velocity and pressure at 0.75 m above the bottom.

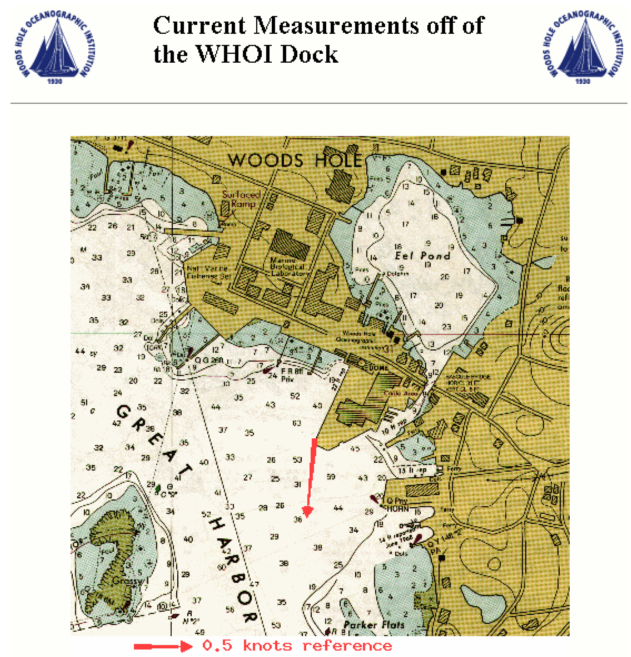

Fig. 9. Data from a MAVS located on a piling at the end of the WHOI dock.

MAVS2 is a talker, not a listener. Resetting its clock or any change in configuration can only be accomplished by sending Control C, the only character that can be detected while the MAVS program is running. After getting the attention of MAVS, a new program can be loaded.

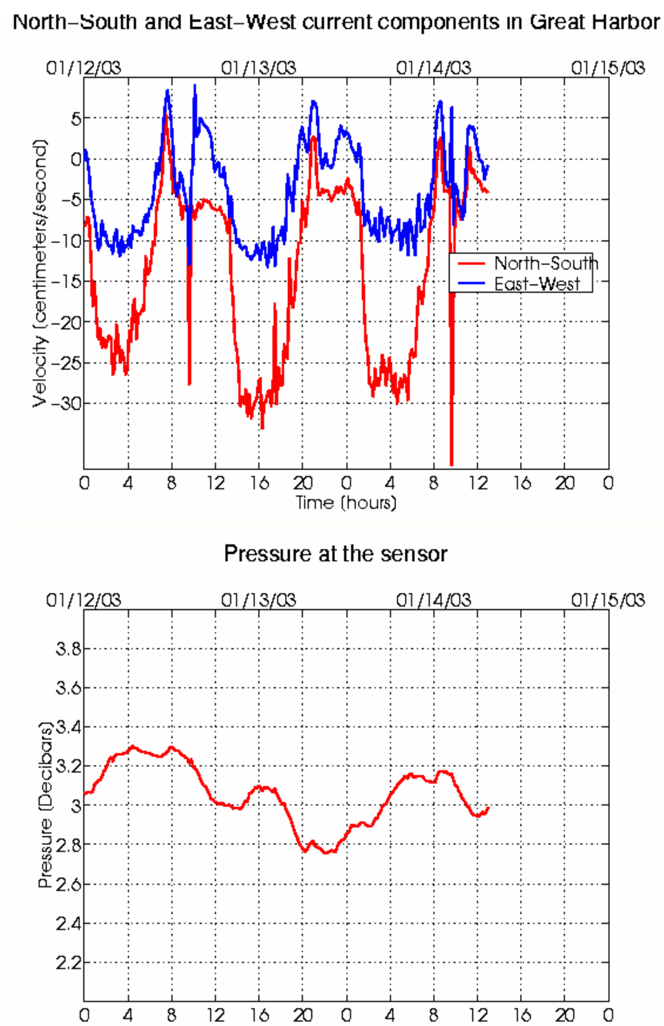

Fig. 10. Time series of velocity components and pressure from a second MAVS hung in the small boat basin at 3 meters depth during an acoustic experiment.

Divers clamped the first MAVS to one of the pilings of the pier. Initially a battery was installed in MAVS to keep the clock running during installation. When an update was required, a new program was loaded, but imperfectly. Control was lost, probably from a failure to return from a subroutine, and diving was required to recover the instrument and regain control. On another occasion when this happened, to avoid diving, the MAVS battery was allowed to die so that external application of power started the program, which was then interrupted before the imperfectly loaded section of code was reached. This strategy was such an improvement over diving as a means of gaining control that batteries are no longer installed in MAVS under the pier. Now, when initial external power is applied, control over the MAVS program can be taken and the clock reset.

Initially only average current data were required. A 15-cm sampling length scale in MAVS needs 1.4 Hz sample rate to prevent aliasing for velocities up to 20 cm/s but characteristic eddies in Great Harbor have energy out to a 10 minute period. To simplify the web site display of current data, MAVS was set to average for 10 minutes and only report this result. In August 2002, a new requirement to retain high frequency was achieved by logging 1.4 Hz data for 10 minutes. This longer file was then transmitted by ftp to the web server.

Acquiring two asynchronous serial data streams posed only one problem for the minimal PC 104 stack assembled in the watertight box on the pier. Opening a second COM port caused conflict with the interrupt demanded by the network card. A new network card solved this problem.

One MAVS was strapped to a bracket spacing it 1 m SW from the 1-m diameter south-westernmost piling of the pier. While this gave the sensor a wake-free exposure to the dominant SE tidal current through Great Harbor, its proximity to the steel piling made the magnetometer compass read the wrong direction. Manually correcting the compass offsets while watching the direction of flow restored the correct direction.

Pressure and temperature as well as horizontal speed and direction were recorded (Fig. 10). Although all three velocity vectors, pressure, and temperature were measured at 1.4 Hz, only averages of horizontal velocity, pressure, and temperature were displayed on the web site. The potential to produce directional wave spectra from the measurements was an attractive possibility. By switching output configuration to Cartesian velocity components, directional wave spectra could have been computed but no waves of period sufficient to be detected at the three-meter depth (below dangers from shipping) penetrate Great Harbor except during hurricanes. Directional wave spectral computations are to await the deployment at MVCO.

The second MAVS was suspended from a rope so it could be moved close to acoustic experimental arrays at which environmental data were needed. This kept it away from severe magnetic influence of pilings. It was only lowered two-meters below the surface with a consequent higher fouling rate. Fig. 11 shows biofouling on the sensor when MAVS stopped measuring current after two months in late summer.

C. MAVS2 Instruments

Recycled MAVS2 current meters were used in these deployments. Sensors were recovered from instruments with damaged electronics and combined with MAVS2 electronics replaced on commercial upgrades to MAVS3 electronics boards. Several damaged sensors were repaired with fiberglass and epoxy. Pressure sensors were added to two current meters.

MAVS2 current meters are appropriate for cable connected applications where continuous power availability obviates the inability of MAVS2 to power down between measurements with consequent limited battery driven duration [7].

Fig. 11. MAVS recovered after two months at 2 meters depth. Acoustic current measurements had stopped due to fouling.

Pressure cases suitable for less than 2000 meters were acceptable for the observatory applications and upgrades to deep (6000 m) pressure cases made sensors and cases available. Not all sensors could be restored to service and some current meters had neither compass nor memory, acceptable for the fixed application on the piling where magnetic influence made the magnetometer compass useless. No logging is required in the current meter for any observatory application.

IV. Conclusions

The target of obtaining wave and current observations on the MVCO is not yet realized although the pieces have been assembled and tested. The recounting of the technological hurdles for connecting to the observatory may be useful to others and also serve as a guide for those of us on this project. Meanwhile, the Dock MAVS continues to return data accessible on the web (barring fouling by unremoved marine growth). Removal of the cables at the ASIT from the previous experiment will permit connecting the first MAVS to the ASIT and availability of ship time will permit the installation of the second MAVS at the 12-meter node.

Acknowledgements

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