Measurements of Waves and Current in Support of Coastal Projects on Nantucket and Martha's Vineyard

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***Abstract*- MAVS acoustic velocity sensors have been deployed in the surf zone at Madaket Beach, Nantucket and on a dock piling at Oak Bluffs, Martha's Vineyard since mid-winter of 2006. Power is supplied to each instrument through a dedicated cable connection and data are returned through this tether to PCs for logging. The current meters report velocity, pressure, temperature, and turbidity in real-time to support continuous monitoring of wave and sediment conditions as they impact beach processes or velocity and pressure for wave conditions in support of marine construction.**

I. Introduction

Fluid velocity measurements resolve currents and waves in the ocean. The Modular Acoustic Velocity Sensor, MAVS, measures flow by differencing travel-time of oppositely directed acoustic pulses along four axes in a 10-cm sensor [1]. Sound transmission is relatively unaffected by suspended sediment or by small bubbles so the acoustic travel-time technique is well adapted for coastal and surf zone measurement of current and waves. Since coastal erosion is a surf-zone dominated process, the utility of making velocity measurements in the surf and relating it to wave conditions is great. Nobska Development, Inc. [2] has developed directional wave spectral analysis software for use with MAVS that uses either horizontal velocity with pressure or 3-D vector velocity to generate directional spectra of surface waves in water up to 20 meters deep from bottom mounted instruments [3]. MWAVES, as this software is designated, analyzes several-minute bursts of velocity, or of velocity and pressure, to produce a statistical representation of wave state. In autonomous deployments, these bursts of typically 4096 samples are triggered at time intervals of 20 or 30 minutes and the data are logged to Compact Flash memory for post deployment analysis. These data are useful for determining what happened in the past and for coastal process studies but are of no benefit to response personnel or homeowners threatened by conditions that develop in real time. Nor are they useful to construction contractors who need to know wave conditions before going to a marine site for surface work or diving. Thus the adaptation of MWAVES to a real-time analysis program was undertaken and is being used to produce wave statistics in real time in two locations; the first at Madaket, Nantucket along a sand beach, the second at Oak Bluffs, Martha's Vineyard on a ferryboat pier.

II. Deployment Sites

A. Madaket, Nantucket

Coastal erosion is a significant and continuing threat to private and public property, including homes and lighthouses, at a number of locations on the island. Remediation efforts, where they have been permitted, have provided only temporary relief. The experiences of communities along most of the eastern seaboard have been similar. An installation at Madaket is being used to study sediment transport at an active and energetic site in detail over an extended period of time. Our goal on Nantucket is to record and study the interactions of waves, currents, and sediment both before and after a possible remediation effort.

Two MAVS instruments equipped with pressure and turbidity sensors were emplaced on jetted pipes off the beach at Madaket in the surf zone in January, 2007 and cabled to a Portable Research Laboratory (PRL) on shore. Each cable provided power to a MAVS and returned data from that MAVS to shore for service on the Internet. Data were continuous since total energy for a cable-connected system is not an issue. The amount of data acquired over many months is, however, an issue despite the cost of storage media being almost insignificant. Analysis to convert the data into information and sorting and selection of the results takes effort, a cost well known to those involved in observatory science. Directional wave-spectra statistics at the time of acquisition and on the previous day or week of sampling is the information needed. Thus the need for Real-Time MWAVES so that statistical summaries of each burst of data can be stored and presented compactly and can be understood quickly for decision making. Although data has been streaming ashore from February 13, 2007 to the present (August 7, 2007), up to now only the raw samples have been stored on servers. From these, selected pieces of these data have been analyzed but no continuous process of analysis has been employed. Thus the demand for Real-Time MWAVES is growing and its development has been given high priority.

Beach frontage at Madaket has eroded during recent storms; several houses have been pulled back from the shore, and others have been lost to the sea. However, not all the storm-driven sand transport has been bad. Recent (August 4, 2007) events have added sand to a beach front that formerly had lost all of its sand and moved the shore front 25 meters farther to seaward. During the Valentine's Day northeaster storm of 2007, the wave-suspended sand started to move northwest toward the detached island of Tuckernuck but six hours later, the sand movement changed direction and for the next five days the sand moved from the direction of Tuckernuck Island towards the Madaket beach where houses had been in danger of falling into the sea [4]. Other issues recently have developed near Madaket at Sheep's Pond, about a mile east of the Madaket site. More measurements are needed there as well.

1) Shoal Modules: Grounded shipwrecks are eventually connected to the beach by sand by a process that deposits littoral transported sand at an interruption in the alongshore bathymetry. Artificial interruptions less permanent and costly than groins or jetties can be used to build this sand deposit in selected locations. Shoal modules, barges ranging from 7 meters to 100 meters in length, can be sunk off a beach at risk and later re-floated for use at another location. The process of sand deposition is somewhat controversial and temporary shoal modules are preferable to permanent structures for this reason alone. Wave conditions and current during deposition created by shoal modules is necessary to document the experiment. Real-Time MWAVES is a compact way to convert raw data to information, understandable by the public and civil engineers alike. So these new deployments at Sheep Pond shall be equipped with MAVS current and wave meters on jetted pipes as at Madaket with shore-connected cables to power them and bring the data ashore. There, the data will be stored on servers but also processed by Real-Time MWAVES. The statistical directional wave measurements and suspended sand observations will be available on the web site so the public is informed and can estimate transport of sand along the beach.

2) Public Interest: Permission is being sought to sink shore modules within or just outside the surf zone. The modules are intended to modify the along-shore transport of sand so that beach width increases. There is considerable local interest in this project and in the study, so the ability to provide results, preferably in easily interpreted plots, on a website and in real-time is required. To support the study, archiving the data and providing a time history of the calculated results are also required.

B. Oak Bluffs, Martha's Vineyard

The Steamship Authority runs a ferry boat from Woods Hole to Oak Bluffs for passengers and cars during the summer months. The Oak Bluffs terminal is a pier on pilings exposed to waves from the north through east. It is vulnerable to northeast storms, which often blow strongly from the northeast for several days and generate destructive waves such as those experienced during the Patriot's Day northeaster of 2007 (April 14, 2007) when the decking of the pier was damaged. At Oak Bluffs, dock replacement, including new pilings, by marine contractors is scheduled for late 2007. Operations will involve barges, boats, and divers. The Authority and the contractor need to know when the wave environment is likely to halt or hamper operations and when it is safe and reasonable to call in workers. The Authority further requires a time-series of wave statistics to determine the numbers of working and weather days over the duration of the contract so that they can accurately assess any cost overruns. These needs are common to most marine construction projects. As with the Madaket project, real-time calculation and display of the wave statistics and directional spectra combined with an archived time history of the results meets these needs.

In March 2007, a MAVS instrument was mounted on a piling of the Oak Bluffs pier with a cable connecting it to a toll booth at the base of the pier. This toll booth houses a laptop computer with broadband connectivity to the Internet and power to run MAVS. Issues with firewalls were overcome to allow access from Woods Hole to the continuous data stream from MAVS. Real-Time MWAVES is now being implemented on these data for inspection of wave statistics by contractor and client alike in near real-time indefinitely.

III. Internet Connectivity

Observatories for ocean monitoring arise, in part, from our ability to be connected by Internet to remotely located sensors. There are obstacles in some installations to this connectivity, notably the layer of water in the deep ocean between the sensor and the relay satellite. Cables are being laid from some offshore observatories to bring the signals from sensors ashore where connection to the Internet is possible. Our applications at Nantucket and Martha's Vineyard are relatively straightforward from this vantage point but they are still magical to many of us. However, service of data and information through a web site on the Internet is becoming standard. This is a service that we assume can be bought. For the purposes of this paper, producing the information for service on a web site will be the task.

Within the firewall that permits us access to the data from the MAVS instruments, we can collect the data stream remotely, but this currently is less efficient than processing the data with Real-Time MWAVES directly on the laptop computer at the end of the cable from the MAVS instrument. Thus the development task will be constrained to adapting MWAVES to processing a continuous data stream remotely.

IV. MWAVES

To achieve these goals we began with MWAVES Directional Wave Spectra Software. This package was previously a strictly post-processing tool for MAVS measurements. It was relatively straightforward to add a loop behavior that could load and process data from a dynamically updated data file, produce plots, and archive the calculated wave statistics. The processes within the loop were identical to those carried out in post-processing, so the only difficulty was providing the inputs and implementing a looping call.

The missing and more difficult piece was a necessarily independent and possibly asynchronous process that could manage the instrument, receive and archive the serial port data stream from the instrument, and dynamically produce the data file processed by the modified MWAVES. Building a real-time website is then a simple matter of linking the plot files normally produced by MWAVES.

MWAVES requires files that are produced by MAVS as decoding information for the binary data files stored on the Compact Flash logging card. Real-Time MAVS, cable connected to shore, does not have an installed logger so these files do not exist and must be generated by Real-Time MWAVES for use by the MWAVES program. These are the Config.bin and Deploy.bin files describing which sensors are enabled, their calibration constants, and the deployment parameters of data format and sample frequency. Real-Time MWAVES must generate these files for MWAVES. Finally, Real-Time MWAVES must chop the continuous stream of data from MAVS into bursts of 4096 samples for processing by MWAVES. In consideration of buffer size limitations on the laptop PC running Real-Time MWAVES, burst-length may be restricted to a sub multiple of 4096. The formation of the directional wave spectral estimates actually uses sub multiples of the burst-length, such as 256 samples, for the FFT computations. These individual spectra are then averaged to reduce the error bars on spectral amplitude at a cost in spectral resolution. This technique increases the number of degrees of freedom in the estimate [5].

MWAVES is the engine inside Real-Time MWAVES that does the directional wave spectrum of each burst and outputs significant wave height, period of the significant wave, and direction of that wave to a statistics file. Each burst also produces a contour plot of direction and spectral density for all of the wave components and the spectrum of these waves. Fig. 1 shows one such screen.

V. Real-Time MWAVES Processing

The data stream from MAVS is cut into burst length pieces with recognition of record gaps and a counter. This is done simultaneously with the MWAVES processing, a task that is not standard for Matlab routines on which the directional wave spectra are computed. However a multitasking environment is required to acquire and process the data simultaneously. Next, the data are archived for post processing if necessary. Finally, the statistical summary is formed and placed in a file for access from a remote server. Fig. 2 indicates these modules.

Data are archived on the laptop computer at the shore station and the stream of data is divided into blocks of 4096 samples. These are processed by MWAVES. MWAVES produces Directional Wave Spectra and Statistical Graphs of wave conditions for the preceding week. These are both available on the Internet. The statistical data are archived and these and the MAVS data are also accessible by Internet from the laptop computer. Fig. 3 is one such display of Statistical Graphs.

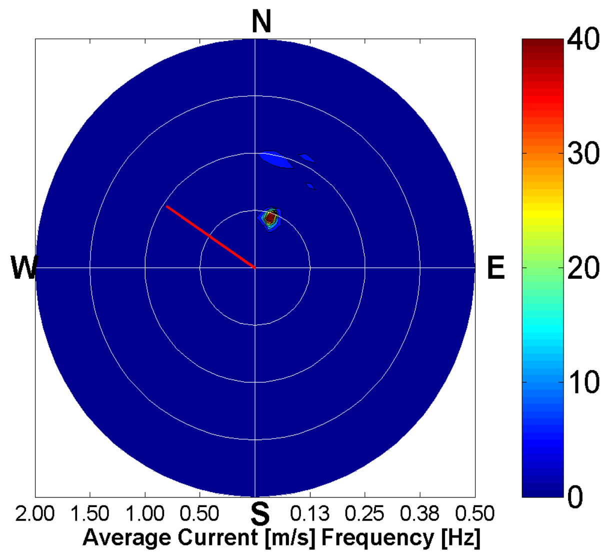

Fig. 1. The MWAVES display screen consists of a directional wave spectrum showing wave power density as a function of angle and frequency and current magnitude and direction (red line).

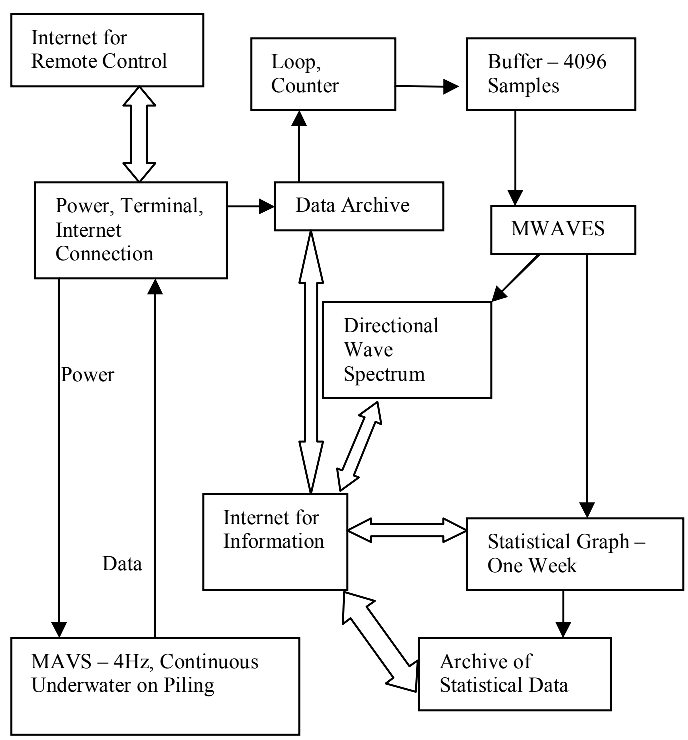

Fig. 2. Modules are displayed of Real-Time MWAVES with the MAVS, Shore Station, and Internet connections shown.

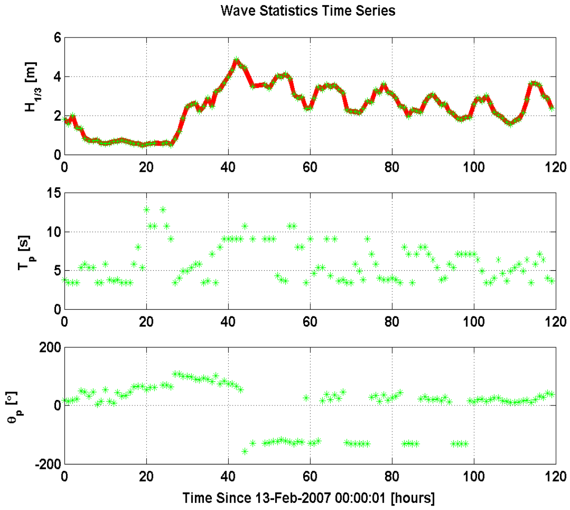

Fig. 3. The Statistical Graph presents a day to a week of significant wave height, period of the most significant wave, and direction of propagation of this wave. MWAVES produced this graph.

VI. Conclusion

Real-Time MWAVES produces directional wave spectra from continuously sampling MAVS flow-measuring instruments that are cable connected to shore. The statistical plots of significant wave height and period over days to weeks permit operators to document the wave conditions at a construction site and homeowners to assess the risk to their beach front homes from a storm during the event.

Installation of MAVS instruments with Real-Time MWAVES can provide the equivalent for the surf zone of weather measuring sensors for the atmosphere.

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