Measurements of Surf Zone Currents and Waves In Support of Madaket and Sankaty Head, Nantucket, Beach Nourishment

Albert J. Williams 3rd, *Fellow IEEE*, Archie Todd Morrison, III, *Member IEEE*,
and Joseph E. Farrell, Jr.

***Abstract*— Coastal sand bluffs and cliffs on the Atlantic seaboard of North America frequently regress, forcing home drawbacks and lighthouse relocation such as that facing homeowners at Madaket and the Sankaty Light on Nantucket. Whether the dominant cause of bluff and cliff calving is erosion of beach at the base from high tide waves or exceptional high water currents or if it is rainfall induced, increased sand on the beach is unlikely to be harmful and may reduce the rate of regression. Evidence of sand spit building from a wrecked clam boat at Sankaty Head beneath the lighthouse suggests that the regression rate might be reduced to the point where relocation of the light is less urgent if barges could be sunk to cause sand to accrete and build the beach at this point.**

Measurement of suspended sand turbidity, along shore current, and waves at 3 m and 4 m depth is being undertaken with two monopod emplacements of MAVS current and wave sensors. Presently these are installed off Madaket at the western end of the island where beach regression is severe. These instruments are powered from shore and return data by cable at 4 Hz for access by Internet. A webcam at the Madaket site supplements the data record on the Internet so that conditions of tidal state, sand bar building and exposure, breaker line, and sand nourishment can be monitored remotely.

Surf zone wave and current measurements are generally high maintenance installations with wave forces tending to uproot and overturn support structures. Cable connections can be dragged alongshore and broken. In this installation, a monopod was employed to reduce the horizontal area of the support structure subject to upward force by waves and chain-weighting buried the cable to reduce lateral drag. Two locations offshore from the region of concern permit shear in the alongshore current to be detected and difference in wave states captured.

Winter storms are important causes of beach sand loss or possibly deposition and this set of observations is designed to correlate current and wave state with such events. Northeast storms are assumed to be the most serious drivers of beach processes here on the coast of Massachusetts but these are typical of sand beaches from Maine to Florida. Observation of the Valentine's Day northeast storm of 2007 represents these processes at Madaket and the extension of these measurements to Sankaty Head may be useful for other locations where cliff regression has endangered lighthouses. Remediation by barge sinking for beach nourishment is planned to follow with similar monitoring of current, waves, and beach condition.

***Index Terms*— Beach nourishment, current measurement, shore processes, wave measurement.**

I. INTRODUCTION

Current and wave measurements in the coastal zone are useful for understanding the motion of sand including erosion and deposition along beaches in response to natural processes and to human intervention. It has been observed by one of us, Farrell, that grounded shipwrecks off a sand beach are inevitably connected to the beach by sand in a matter of a few weeks or months. This leads to the hypothesis that local beach nourishment in particularly vulnerable locations might be implemented by grounding a barge outside the surf zone off the region of concern. The alongshore sand transport during storm events or even during normal tidal excursions is interrupted and accretes around the obstruction. Orrin H. Pilkey of Duke University has long argued against the construction of groins along sand beaches [1] and, through his influence, North Carolina has banned their construction; but point remediation for vulnerable regions remains a viable option and the less costly and quicker emplacement of barges at those points represents a strategy worthy of study. Although the outcome is to be tested by beach nourishment success a supporting study of the current, wave, and suspended sediment climate with and without barge emplacement is sensible and the study reported here is the first stage of such a project.

II. NANTUCKET EXPERIMENTAL INSTALLATION

A. Location

Nantucket Island, located off the coast of Massachusetts, is a relic of the last glaciation in New England. Largely sand, it also has bodies of clay such as the Sankaty Head cliff. Ocean currents have shaped Nantucket into a crescent shape with

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A. J. Williams 3rd is with Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA (phone 508- 289-2725; fax: 508-457-2194; e-mail: awilliams@whoi.edu).

A. T. Morrison, III, is with Nobska Development, Inc, Woods Hole, MA 02543 USA (e-mail: atmorrison@nobska.net).

F. E. Farrell, Jr. is with Coastal Recovery by Farrell LLC, Nantucket, MA 02554 USA (e-mail: jfarrell@resolvemarine.com).

Sankaty and Siasconset to the southeast and sand beaches extending north and west around the island. Madaket at the western end is almost connected to several islands that continue the sweep to the northwest. Tuckernuck, the closest, has summer homes but Muskeget farther to the west is uninhabited. Sand transport along the southwest beach to the northwest or the lack thereof determines whether Madaket remains attached to Nantucket or spawns additional islands. Nantucket Shoals lie seaward of Nantucket out for more than 30 miles and have a moderating influence on storm waves. Deep channels inside shallow bars also are characteristic of the Sankaty Head location as shown in Fig. 1. Shifting bars at Madaket are also important for the shoaling wave heights so the chart in Fig. 2 is not exactly representative of the inshore bathymetry during the observations presented here.

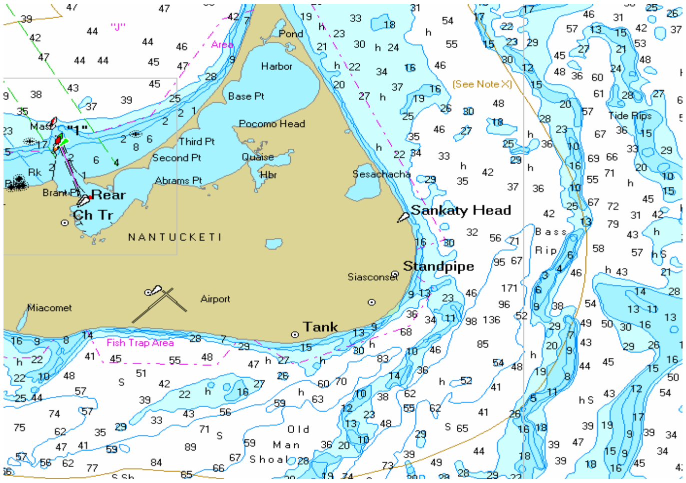

Fig. 1 Sankety Head, Nantucket where the 30 meter cliff that is eroding jeopardizes the lighthouse. Offshore bars protect against large waves in storms. Possible shoal module emplacement to nourish the beach is proposed along with current and wave measurements to understand the accretion process.

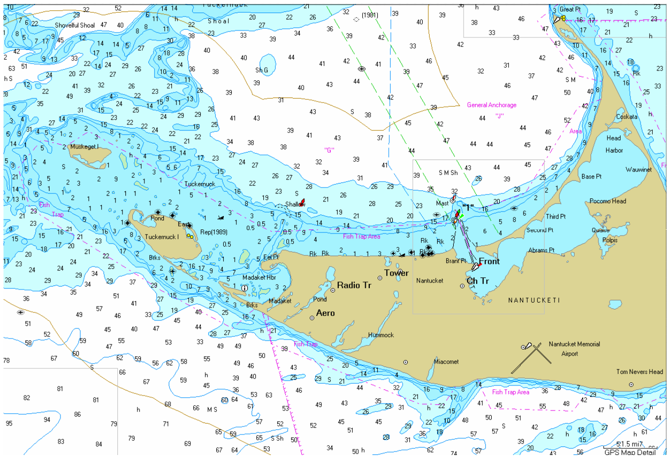

Figure 2 Madaket at the west end of Nantucket Island where the current meters were emplaced.

A Portable Research Laboratory was outfitted to support the instrumentation for the Nantucket observations. Fig. 3 shows this PRL on its trailer. The trailer was parked in an access road to a beach house that has washed away and electricity and Internet connectivity was provided from a utility pole. Fig. 4 shows the interior of the PRL with the computers and weather station equipment. Heat, refrigerator, humidor, and bed make it habitable even in winter weather.

Fig. 3 Portable Research Lab on a trailer for emplacement at a beach to support the offshore instruments.

Fig. 4 Interior of PRL with weather station and computers for logging data.

B. *Instrumentation*

MAVS current meters [2] measure 3-D vector velocity in a 10 cm diameter volume using differential acoustic travel time [3]. Temperature and pressure measurements are added to the velocity measurements to provide a standard wave measuring instrument. For the Nantucket measurements, optical turbidity was added with a Seapoint optical backscatter sensor [4]. Although the Seapoint sensor requires calibration with actual material that it senses to provide true engineering units of suspended load, it is reliable as a relative measure assuming the suspended material is similar during storm and between storm events. This is not strictly true since during storms, larger grains will be suspended into the optical sampling volume after the fines have been blown off, but it is a strong indicator of suspended load for qualitative purposes.

MAVS can be powered internally and record data on a compact flash card for durations of months if burst sampling is employed [5]. However, in the application on Nantucket, the instruments were cable connected to shore for power and data recovery. Each instrument was strapped to a pipe as shown in Fig. 5 with a spacer for alignment with the pipe axis. MAVS was mounted sensor up with the measurement volume above the housing at a depth of approximately 1.7 m below the surface at low tide. More importantly, it was mounted 1.7 m above the bottom since the tidal range and the storm surge change the depth below the surface. The pipe was jetted 3.3 m into the bottom from a skiff (Fig. 6) that was launched January 22, 2007 in an incredibly flat sea off a beach that generally has breakers. The cable was tied wrapped to 3/8" galvanized chain every 1.5 m and the chain was continued across the beach to a strong point to resist drag from exposed sections in the surf if such might occur. The beach passage was trenched as shown in Fig. 7. As of February 28, 2007 the installation was intact despite bar formation and disappearance and the pipe twisting 90º around the vertical axis and inclining 26º in the SE direction. Since the magnetic heading and tilt are measured and used in the computation of direction of current [6], the rotation and tilt don't cause a measurement error but it is instructive to know about motion of the monopod. During high waves, there was also some acceleration of the sensor indicated by vibration of the tilt meter which consists of a two-axis linear accelerometer. This is shown for the storm waves in Fig. 8.

Fig. 5 MAVS current meter on pipe preparatory to jetting into the sand. The acoustic travel-time sensor is a pair of rings at the top (on the right in the photograph) where only the lower ring is visible.

Fig. 6 Deployment of cable to the installation site 250 meters offshore at Madaket on a calm day. Electrical cable is tie wrapped to 3/8" galvanized chain every 1.5 m.

Fig. 7 Trenching MAVS cables across the beach. Sandbar is visible offshore.

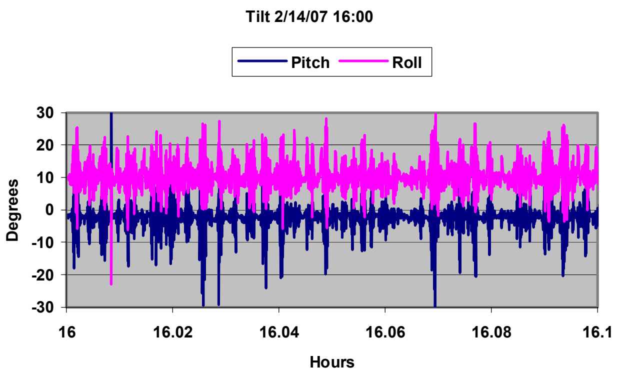

Figure 8 Tilt measurements from MAVS on the jetted pipe during the peak of the Valentine's Day storm. Wave impacts cause acceleration sensed by the linear accelerometer tilt sensor.

Although the data stream in continuously from both MAVS instruments and are captured on a pair of PCs, the serving of the data has not been completed as of the writing of this paper. All data are archived on a large server and 2048 record bursts were extracted for each hour extending from February 13 to February 18, 2007. Only one sensor was available at this time from the server. Wind and weather data are also recorded for eventual real time display along with the current and wave measurements. The temperature and turbidity are also to be part of this display. Partly this is to be open about the work ongoing at the beach and partly it is to allow interested parties to use the data for their own purposes. At the moment, it is useful for analysis of the storm and the effect of shoal modules to be emplaced later.

C. Valentine's Day Northeaster

A large disturbance developed in mid-February that was christened the Valentine's Day storm of 2007 by weather persons and newscasters. Although the snowfall experienced in Vermont was substantial, little snow fell on Cape Cod and the Islands of Martha's Vineyard and Nantucket. But the wind blew from the west and northwest and later from the southwest for five days, reaching to gusts of 50 knots on the beach at Madaket. During those high wind conditions, the sea was confused with the local sea at an angle to the large swell propagating shoreward. Fig. 9 is a wave spectrum showing the several components of the sea with a 9-second wave dominant but a 4-second wave present. The directional spectrum of Fig. 10 shows that the long period waves are directly shoreward at a bearing of 025° while the shorter period sea is more northerly. The significant wave height rose rapidly at hour 40 from February 13 00:00 (February 14 16:00) when the storm was delivering the swell from its offshore generation region. This is illustrated by the 5-m significant wave height, only possible because of the setup that made the water deep enough for such a wave to propagate. During this time and for several days thereafter, the troughs of the waves exposed the MAVS acoustic transducers causing several seconds of lost signal. On February 15 several bursts lasting 8 minutes had as much as half the measurements (4 minutes) in air. In Fig. 11, the significant wave height can be seen as well as the tidal modulation of the significant wave height as the depth of water varies.

Figs. 9, 10, and 11 are derived from MWAVES [7] using pressure and two horizontal axes of velocity. The wave statistics plot of Fig. 11 represents the period of the greatest significant wave so with small shifts of amplitude between mixed wave components, the significant wave period may suddenly jump. However, all of the components are present and acting upon the sand bottom to suspend and later transport sediment.

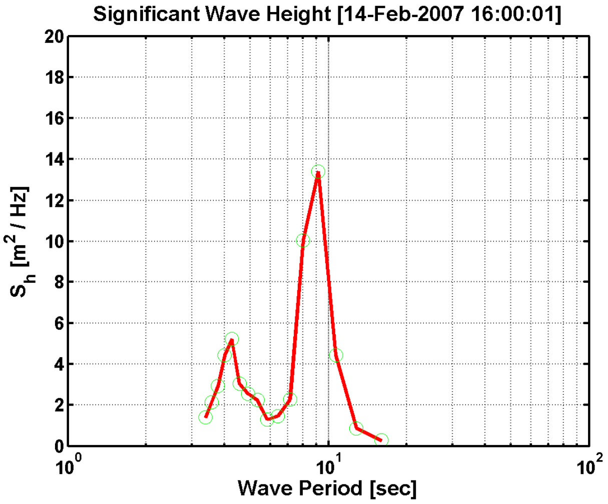

Fig. 9 Significant wave height during the peak of the Valentine's Day storm with a 9-second wave dominant over a 4-second wave.

Wind direction and storm setup along the beach create alongshore current. The current direction was NW on February 14 but turned SE on February 15 and remained that direction for the next three days. This is critical for sand transport since the waves suspend the sand but the current transports it.

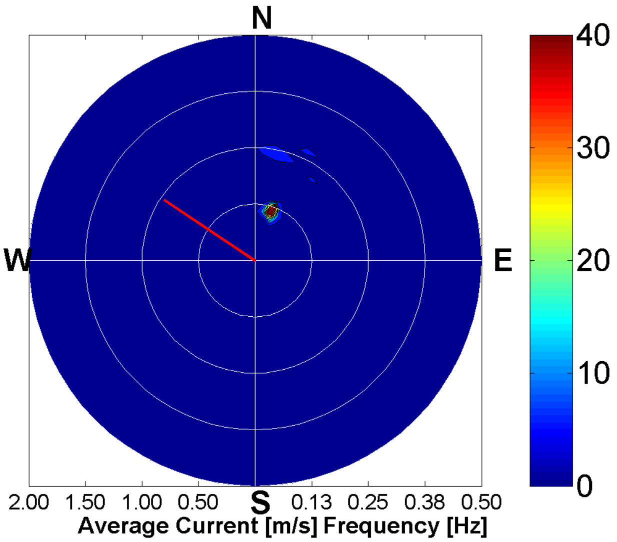

Fig. 10 Directional wave spectrum during the peak of the storm on 14-Feb-2007 16:00. The red bar is the current, 1.00 m/s NW, while the major swell is NNE at 0.13 Hz and the minor sea is nearly N at 0.25 Hz.

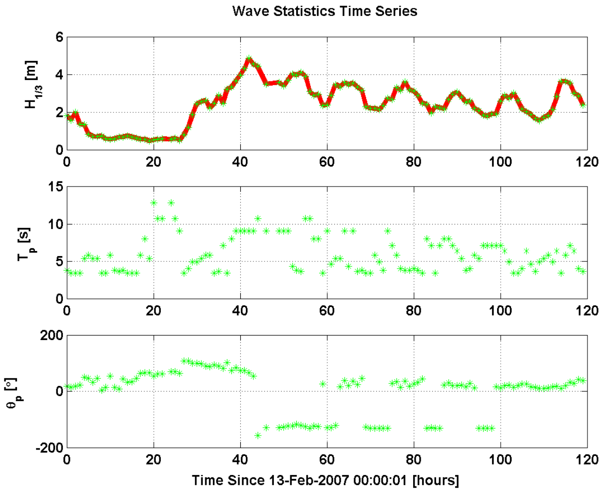

Fig. 11 Wave statistics from 8-minute bursts each hour over the duration of the Valentine's Day storm. At hour 40 (14-Feb-2007 16:00, the significant wave height reached 5 meters. In subsequent days the significant wave height was modulated by the tidal depth range. Period of most significant wave jumped abruptly when a minor wave overtook in height a major wave.

D. Sand Transport

The Seapoint optical backscatter sensor measures the light backscattered into a detecting photodiode from an LED that is directed into the water a distance of several centimeters. If the water is very clear, few photons are returned and those that are returned come from a distance on average. As the water becomes cloudier, the scattering increases, more photons are returned, and they come from a region closer to the sensor in general. Large particles scatter light into a narrow angle while particles at or near the wavelength of light scatter light into a large angle. But in either case, forward and backscatter are greater than 90º scatter and the Seapoint sensor is optimized for backscatter. A larger signal is returned from fine particles than from an equal density of coarse particles. Thus, when a deposited mix of sediment containing sand, silt, and clay particles is first suspended, the original signal is dominated by the fines. But when the waves have been suspending and the current has been winnowing the sediment for an extended time, the fines are so reduced that the signal may be primarily from the coarse sand particles that remain. For this reason, it is likely that the signal from the Seapoint turbidity meter overestimates the concentration of suspended sediment initially in a suspension event but underestimates the concentration subsequently. In the MAVS record, the measure of turbidity is simply millivolts from the Seapoint sensor since to convert to sediment concentration would require more knowledge than we have. Suffice it to say that the later portions of the storm are the portions with the largest signal despite the fines, presumably, having been winnowed, and thus the transport estimates are biased conservatively towards less apparent transport than actually occurred.

Fig. 12 is the signal from the Seapoint sensor in millivolts indicated as Turbidity arbitrary units while the SE transport is the product of turbidity with average horizontal current speed and the direction supplies the sign. This is cumulatively summed for the total transport. It can be seen that nothing happens before the waves stir up sediment and the turbidity rises. Then the current carries the suspended sediment NW for about 4 hours but after that the current increases and carries the suspended sediment SE through the period until the concentration dies away on February 18

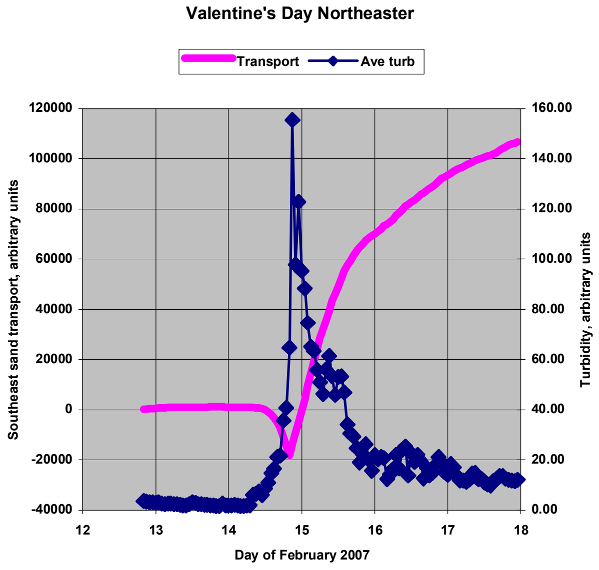

Fig. 12 Turbidity increased rapidly with the waves of the Valentine's Day storm as shown in the blue. The product of turbidity and current with the sense of direction being positive for SE direction is flux. The integral of flux is the sand transport in pink.

III. CONCLUSION

A system of instruments cabled to the shore can monitor current, waves, and turbidity in support of coastal remediation efforts. These data can be recovered continuously through major storms and show sediment transport in response to waves and current. A simple monopod installation with chain weighted cable that self buries and is trenched across the beach survives these storms at least for awhile. The instrumentation is robust to minor alignment alteration by the current and wave action. In the future, these data will be visible to the general public from a web site. Installation of shoal modules (sunken barges) may accrete sand at critical vulnerable regions and the effect of these on the flow and sand transport can be monitored from the shore installation.

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