REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*

2. REPORT TYPE

3. DATES COVERED *(From - To)*

4. TITLE AND SUBTITLE

Real-Time Characterization of Mine Scour Burial at the Martha's Vineyard Coastal Observatory

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
0602782N

6. AUTHOR(S)
Michael D. Richardson, Edward F. Braithwaite III, Sean Griffin, John Bradley, Carl T. Friedrichs, Arthur C. Trembanis, Peter Traykovski

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER
74-6639-05

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Marine Geosciences Division
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/PP/7430-04-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
800 North Quincy Street
Arlington VA 22217-5660

10. SPONSOR/MONITOR'S ACRONYM(S)

ONR

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release, distribution is unlimited

13. SUPPLEMENTARY NOTES
6th International Symposium on Technology and the Mine Problem

14. ABSTRACT
Mine burial by scour was measured in real-time using two cylindrical instrumented mines connected to a shore-based facility at the Martha's Vineyard Coastal Observatory (MVCO). Data on mine movement (heading, pitch, and roll), scour pit geometry, percent burial, and environmental processes responsible for scour burial including significant wave height, period, and tidal height were analyzed daily and presented on the NRL web site http://www7430.nrlssc.naw.mil/bblp/mine/realtimedata/.

Scour pits developed in response to storm generated significant wave heights of up to 2.5-m that occurred within the first 5 days of the experiments. The two instrumented mines pitched (3-9°), rolled (35-55°), and reoriented to align axially (up to 40°) with incoming swell as they rolled into scour pits. The mines were buried level with the seafloor after a second storm. Subsequent storms with wave heights up to 3.5-m were unable to further bury the mines. A comparison of the observed mine burial and real-time predictions http://www.vims.edu/phvsical/ proiects/CHSD/projects/MBP/using a modified Whitehouse -Soulsby wave-induced scour model were nearly identical suggesting mine burial by scour is predictable from bathymetry, sediment type, and measured or predicted surface wave conditions.

15. SUBJECT TERMS
Mine burial by scour, Martha's Vineyard, Minecountermeasures

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Michael D. Richardson
Unclassified	Unclassified	Unclassified	SAR	6	**19b. TELEPHONE NUMBER** *(Include area code)* 228-688-4657

Real-Time Characterization of Mine Scour Burial at the Martha's Vineyard Coastal Observatory

Michael D. Richardson, Edward F. Braithwaite III, Sean Griffin, John Bradley, Carl T. Friedrichs, Arthur C. Trembanis, and Peter Traykovski

Abstract: Mine burial by scour was measured in real-time using two cylindrical instrumented mines connected to a shore-based facility at the Martha's Vineyard Coastal Observatory (MVCO). Data on mine movement (heading, pitch, and roll), scour pit geometry, percent burial, and environmental processes responsible for scour burial including significant wave height, period, and tidal height were analyzed daily and presented on the NRL web site http://www7430.nrlssc.navy.mil/bblp/mine/realtimedata/. Scour pits developed in response to storm generated significant wave heights of up to 2.5-m that occurred within the first 5 days of the experiments. The two instrumented mines pitched (3-9°), rolled (35-55°), and reoriented to align axially (up to 40°) with incoming swell as they rolled into scour pits. The mines were buried level with the seafloor after a second storm. Subsequent storms with wave heights up to 3.5-m were unable to further bury the mines. A comparison of the observed mine burial and real-time predictions http://www.vims.edu/physical/projects/CHSD/projects/MBP/ using a modified Whitehouse -Soulsby wave-induced scour model were nearly identical suggesting mine burial by scour is predictable from bathymetry, sediment type, and measured or predicted surface wave conditions.

Introduction: Buried mine detection is one of the greatest threats facing shallow water Mine CounterMeasures (MCM) operations [1]. The possible presence of buried mines can change MCM tactics from one of mine hunting to one of minesweeping or area avoidance. The ability to predict mine burial both for planning and during operations (strategic and tactical scenarios) is therefore of great importance to Naval forces. Processes known to contribute to mine burial include burial at impact usually in low strength muddy sediments; scour and infilling; bedform migration or transverse bedform movement; bedform morphological alterations, such as changes to shorerise or bar-berm conditions; liquefaction or fluidization of the sediment; and biological processes that scour or promote scour by altering seafloor physical properties.

The mine burial experiment described in this paper was conducted at the Martha's Vineyard Coastal Observatory (MVCO) during the winter of 2003-04. The Woods Hole Oceanographic Institution (WHOI) developed this observatory, off the south shore of Martha's Vineyard Island, to study coastal processes in an area dominated by open ocean conditions [2].

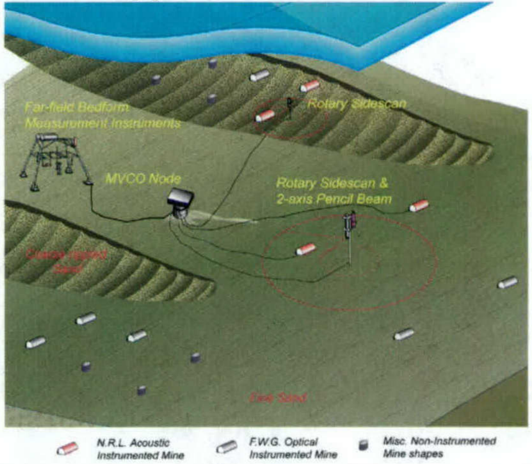

Fig. 1. Cartoon of the relative location of the instrument and non-instrumented mines, rotary sidescan and pencil beam sonars, and far-field bedform measurements instruments to the 12-m communication node at Martha's Vineyard Coastal Observatory.

Instrumented Mines: The cylindrical mines (2.033 m long, 0.533 m in diameter, 1,984 kg m^{-3} density) are constructed of non-magnetic bronze and covered with 112 flush mounted acoustic sensors (1.5-MHz and 3.0-MHz) which are used to determine percent burial (% surface area) and measure scour pit geometry [3]. Acoustic backscatter from sediment suspended in the water column can be used to measure flow and estimate sediment concentrations near the mine. The acoustic sensors have the potential to measure suspended grain size distribution using the two-frequency inversion techniques developed by Thorne [4]. Each mine has 6 pressure sensors which are used to determine tidal heights,

Mike. Richardson and Edward Braithwaite are with the Marine Geosciences Division, Naval Research Laboratory, Stennis Space Center, MS 39529-5004 USA; E-mail mike.richardson@nrlssc.navy.mil

Sean Griffin and John Bradley are with OMNI Technologies Inc., 7412 Lakeshore Drive, New Orleans LA 70124 USA; E-mail sgriffin@otiengineering.com

Carl Friedrichs and Art Trembanis are with Virginia Institute of Marine Science (VIMS), College of Marine Science, Department of Physical Sciences, Gloucester Point, VA 23062 USA; E-mail cfried@vims.edu

Peter Traykovski is with the Applied Ocean Physics & Engineering Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543 USA; E-mail ptraykovski@whoi.edu.

significant wave heights and periods, and when compared to a spatially-fixed reference pressure sensor calculate mine burial relative to the sediment surface. Changes in mine orientation (heading, roll and pitch) are measured with a three-axis flux gate compass and three-axis accelerometer.

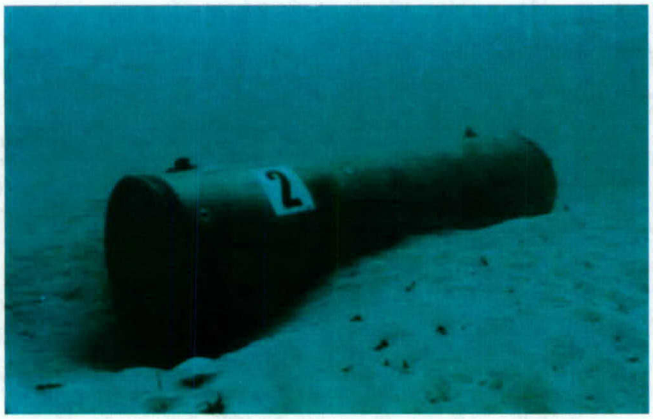

Fig.2. Underwater photograph of Acoustic Instrumented Mine (AIM)

Experimental Description: Four acoustic instrumented mines together with six optical mines and six inert shapes were deployed near the Martha's Vineyard Coastal Observatory (MVCO) 1-2 October 2003 and most were recovered 16-18 April 2004. The observatory (MVCO) consists of a shore station with power and communication facilities connected via buried electro-optical cable to a power and electronics node located 1.0 km offshore in 12-m water depth. Two acoustic mines were connected to the power and communications at the MVCO node to provide real-time burial and environmental data. Only data from the first experiment (2 Oct to 5 Dec 2003) using the two node-attached acoustic instrumented mines is reported in this paper. The first experiment was terminated when the mines were moved on 5 December 2003. Data from the two acoustic mines connected to the communication node were stored on shore-based computers at MVCO, downloaded to the Naval Research Laboratory daily over the Internet, and analyzed to determine hourly values of percent burial, roll, pitch, heading, tidal state, significant wave height and period, and bottom water temperature. The data were then displayed in graphical and tabular form on the NRL web site (http://www7430.nrlssc.navy.mil/bblp/mine/realtimedata/). Later analyzes provided data on percent burial based on acoustic sensors covered, a geometric description of the scour pit, and sediment concentration in the water column. Sediments in the vicinity of the experiment were moderately well-sorted, fine quartz sand with a mean grain size of 0.18 mm (phi 2.5), average grain density of 2661 kg m^{-3} (SD = 11 kg m^{-3}), porosity of 38.5% (SD = 0.7 %) and bulk density of 2042 kg m^{-3} (SD = 11 kg m^{-3}) [5]. An average of 95% of the sediments were sand-sized (by weight) with most grains between 0.1 and 0.35 mm.

Oceanographic Data: Tidal and wave data were measured using the six pressure sensors located at 60° intervals around each mine (Fig 3). Only data from AIM3 is presented as no significant difference between oceanographic data series measured with the two AIMs mines was detected. Tidal, temperature and wave statistics were the nearly identical to time series reported by sensors located on at node of MVCO over the same time period (http://mvcodata.whoi.edu/cgi-bin/mvco/mvco.cgi). Bottom temperature decreased 10° over the 62 day sampling interval (1 October through 5 December). Seven storm events with significant wave heights of 2-m or greater were recorded on day dates 279, 289, 295, 303, 318, 324 and 333.

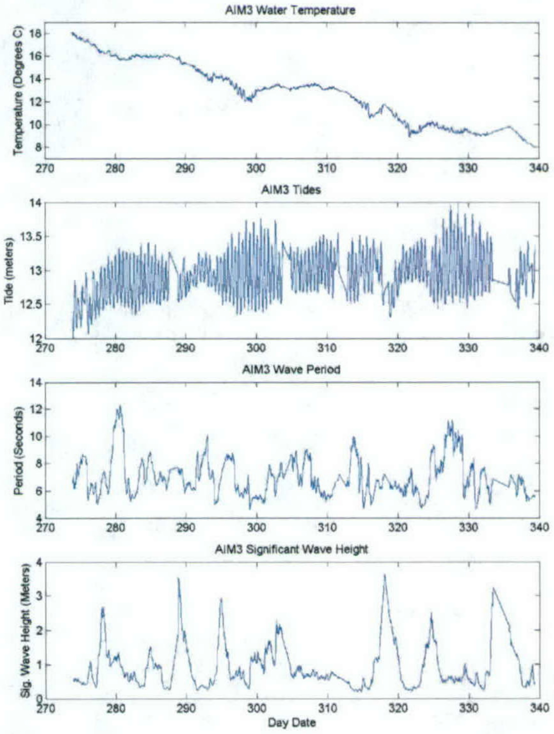

Fig. 3. Summary of temperature, tide and wave data collected by AIM3 during deployment at MVCO between 1 October 2003 and 5 December 2003.

Mine Movement and Burial: Changes in mine orientation (heading, pitch and roll) generally occurred during storm events when significant wave heights were greater than 2 meters (Figs 4 and 5). During the first two storms (day dates 278 and 289) both mines pitched, rolled and changed heading suggesting mines rolling into scour pits. No movement was detected during storms 3 and 4 (day dates 296 and 303) indicating scour pit development was insufficient to reorient the mines. Wave conditions during the fifth storm (day date 317) correlated with movement of AIM3 only. The 6th storm (day date 325) generated lower significant wave heights than previous storms and resulted in only a slight change in pitch for AIM4. The last storm (day date 332) resulted in a change in pitch and heading of AIM3 but little movement of AIM4. Over the 64 day period, the mines rolled roughly 40° (AIM3 clockwise, AIM4 counter clockwise), pitched 3-4°; and reoriented parallel to dominate storm wave conditions (waves from the southwest).

Mine burial was calculated relative to the sediment surface (Figs. 6 and 7) by comparing mean pressure measured with the six pressure sensors around each mine relative to pressure measured at a fixed point on the MVCO node. The calculations assume negligible changes in sediment surface elevation which may accompany larger-scale bedform migrations. Mine burial was also measured as a function of surface area covered (Fig 8 and 9) using the 120 acoustic sensors that covered the surface of the mine. Both instrumented mines buried nearly 40-cm relative to the sediment water interface (pressure measurements) after the first storm (Day Date 278) and an additional 10-cm after the second storm (Day Date 289). Changes mine burial was concordant with changes in mine orientation during the same period and can be interpreted as mines rolling into scour pits. Little change in burial was measured after the second storm suggesting that scour during subsequent storms was insufficient to further bury the mines but sufficient to allow some mine movement.

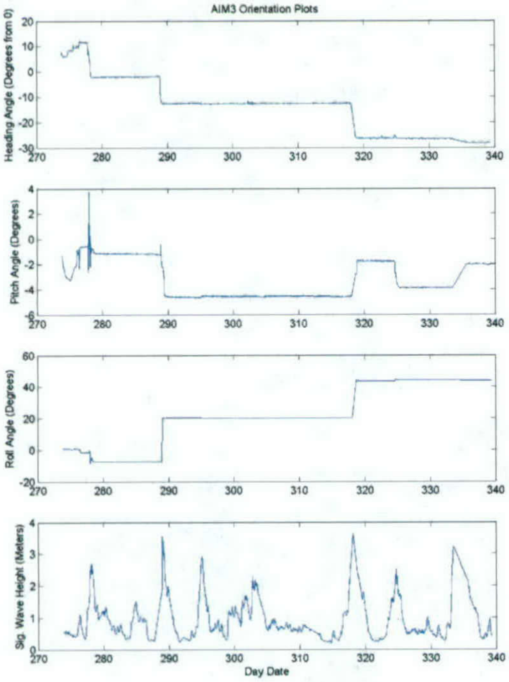

Fig. 4. Changes in orientation (heading, pitch and roll) related to significant wave height of AIM3 over the period of October 2 (day date 274) to December 14 (day date 340) 2004.

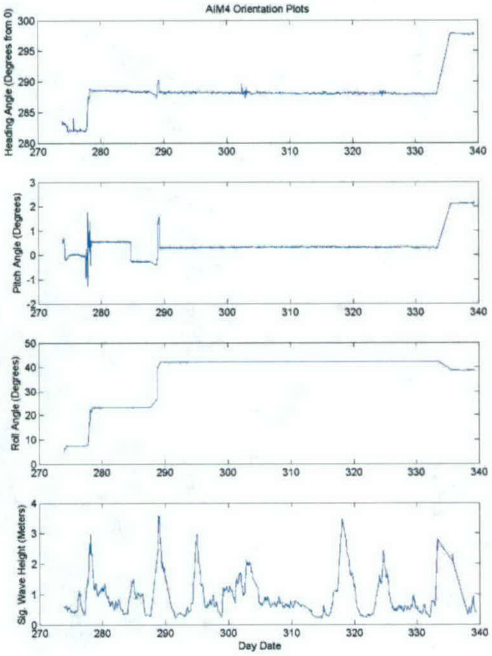

Fig. 5. Changes in orientation (heading, pitch and roll) related to significant wave height of AIM4 over the period of October 2 (day date 274) to December 14 (day date 340) 2004.

Apparent fluctuations in mine burial relative to the sediment surface are probably artifacts of the filtering of pressure series measurements. Burial of the mines measured as surface area covered yielded a much different result with a maximum of 40% (AIM3) to 45% (AIM4) burial compared to near total burial relative to the sediment water interface. It is apparent that only relatively minor infilling of the scour pits occurred after storms and the mines although fully buried rested in larger scour pits (Figs 8 and 9). Sonar images (sector scan and pencil beam sonar) and multibeam surveys of the mines collected by Traykovski et al [6] during the mine burial experiments support the observations made using the instrumented mines. Most of the surface area burial occurred during the first storm which is concordant with the observations of burial relative to the sediment–water interface. Increases in surface area exposed for AIM3 were evident during the second (day date 289) and fifth (day date 318) storms probably as a result of scour. The second storm (day date 289) resulted in increased burial of the surface of AIM4 and a decrease in surface burial occurred during the 5th storm (day date 318). In summary, sediments were scoured away from the mine as significant wave heights exceeded 2 meters and significant scour pits developed. At the height of the storms the mines began to pitch, and then rolled into the scour pits changing heading to axially align with the incoming waves. Scour around the mines occurred during four subsequent storms with significant wave heights greater than 2.5 meters without additional burial with respect to the seafloor. During two of these storms scour significant enough to allow mine movement (pitch, roll and changes in heading) occur and high concentrations of sand-sized particles were detected in the water column (see next section).

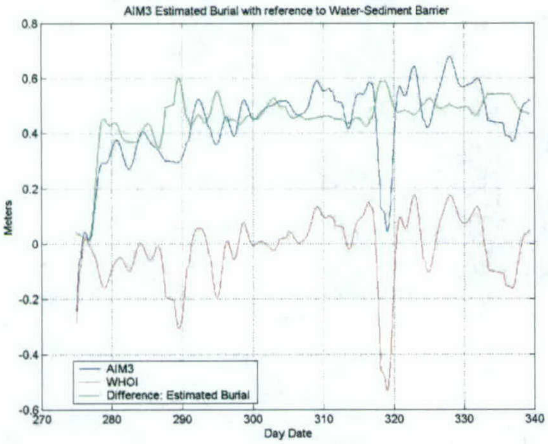

Fig. 6. Mine burial (in meters) relative to the sediment water interface determined as the difference between filtered pressure series measured with six pressure sensors (AIM3) on the surface of the mine and filtered pressure series measured at a fixed point on the MVCO node (WHOI).

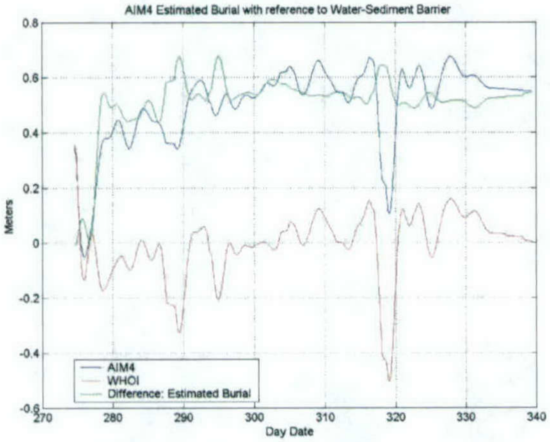

Fig. 7. Mine burial (in meters) relative to the sediment water interface determined as the difference between filtered pressure series measured with six pressure sensors (AIM4) on the surface of the mine and filtered pressure series measured at a fixed point on the MVCO node (WHOI).

Scour Pit Development and Re-suspension Events: The 112 acoustic sensors located over the surface of the mine are designed to characterize the dimensions of the scour pit and determine particle size distribution of sediment suspended in the water column as a result of scour and sediment transport. Although the characterization of particle size distribution in the water column is still being developed, events where sediment particles are suspended in the water column are easily seen in images of acoustic scatter from unburied transducers looking into the water column. Increased scatter due to particles in the water column are evident during all seven storm events (Fig. 10). These data will be used to determine temporal changes in the concentration and size distribution of particles in the water column.

Acoustic reflections derived from transducers directed at the sediment surface can be used to measure the distances between the mine and sediment surfaces (Fig. 11). The scour pit dimensions can then be derived from an analysis of reflection distances calculated from all sensors surrounding the mine and a careful consideration of mine orientation. Changes in mine orientation, especially roll, must be accounted for in developing images of the temporal evolution of the scour pits. Figure 12 shows scour pit development during the first storm (day date 278). AIM4 is sitting in a scour pit at least 20 cm below the sediment surface.

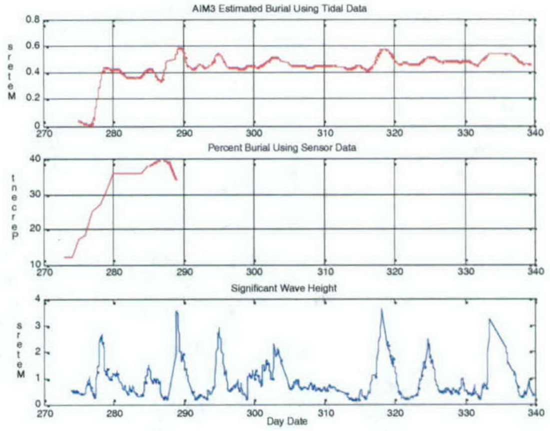

Fig. 8. Temporal relationships among burial measured as depth below the sediment water interface, burial measured by surface area covered and significant wave height measured using AIM3.

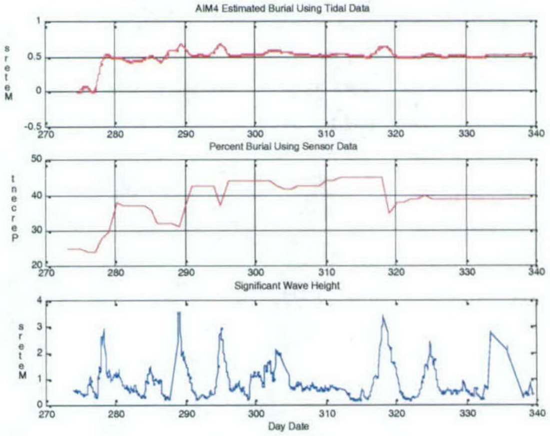

Fig. 9. Temporal relationships among burial measured as depth below the sediment water interface, burial measured by surface area covered and significant wave height measured using AIM4.

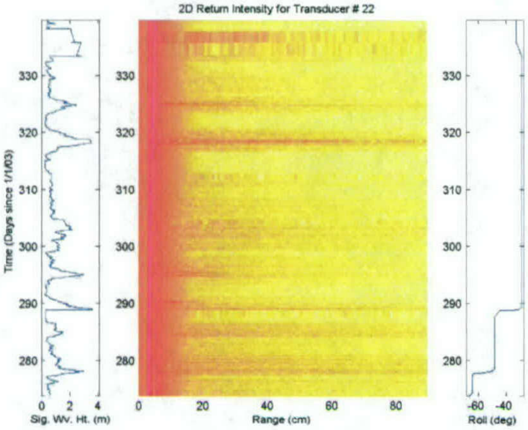

Fig. 10 Temporal evolution of acoustic backscatter strength from a single upward looking 3 MHz acoustic transducer on AIM3. Note the increased scattering (darker intensity of red) at distances of 15-80 cm from the mine surface. Blanking as a result of saturation from the transmitted signal precludes measurements of particle size distribution closer than 15cm from the transducer face. Also included are mine roll (degrees) and significant wave height (meters) measured by three-axis flux gate compass and three-axis accelerometer and pressure sensors in AIM3.

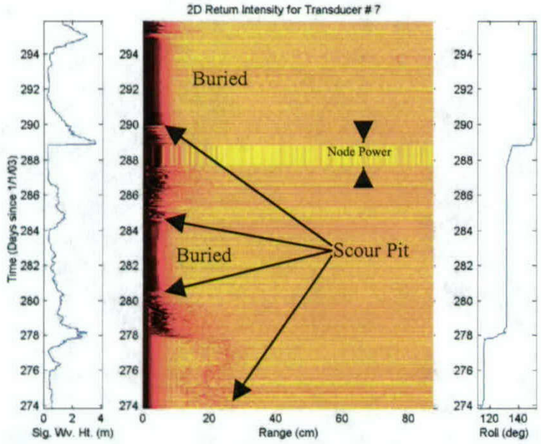

Fig. 11. Temporal evolution of backscatter strength from a 750 kHz a single transducer looking at the seafloor. The distance between the mine surface and sediment surface (scour pit) is easily determined as is the burial state at that surface location. Note the change in distance of the scour pit as the mine rolls into the scour pit.

Mine Burial Prediction: Mine burial was predicted in real-time using a modified Whitehouse-Soulsby [7] wave-induced scour model, water depth, sediment mean grain size, and significant wave heights predicted from the NOAA Wave Watch III wave forecast model. Both 5-day forecasts and burial hindcasts of wave height, bottom orbital velocity, wind speed and mine burial were updated every 12 hours on the VIMS mine burial web site http://www.vims.edu/physical/projects/CHSD/projects/MBP/index/. Wave forecast predictions from NOAA's WaveWatch III model matched both measurements at nearby NOAA buoys and measurements at the MVCO site. Mine burial predictions of both percent of the surface area covered with sediment and burial relative to the sediment-water interface matched burial measured with the instrumented mines (Fig. 13). These results suggest mine burial by scour is predictable and can be forecast based on local bathymetry, sediment type, and measured or predicted surface wave conditions.

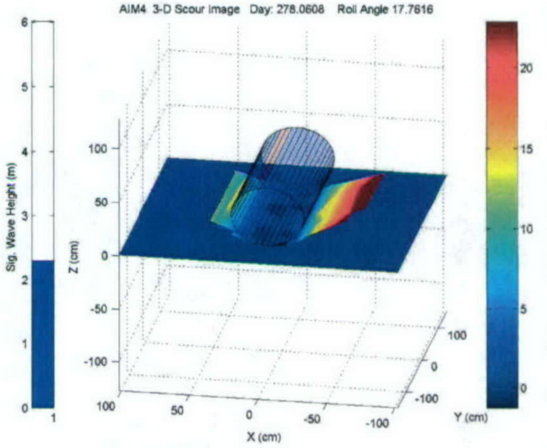

Fig 12. Estimated dimensions of the scour pit surrounding AIM4 based on acoustic reflections (see Fig. 11) from sensors located on the surface of the mine. This image derived from data collected on day date 278.08 (0100 October 5 2003) which was near the height of the 1st storm. The mine's roll was 17.8° from vertical, heading 287.6°, pitch 1.0° and the significant wave height was 2.44 meters. The colors on the intensity bar represent the height of the reflection in cm above the blue reference plane (referenced to the bottom of the mine).

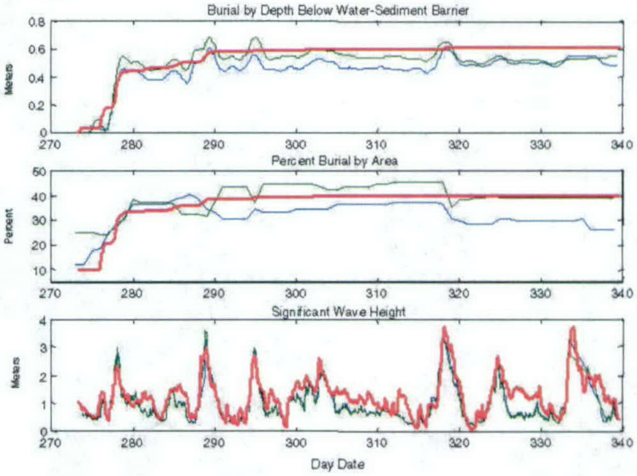

Fig. 13. Temporal relationships among burial measured as depth below the sediment water interface, burial measured by surface area covered and significant wave height. Thick lines (red) are predictions based on WaveWatch III and a wave-induced scour model. Thin lines are observations from AIMs; the green is AIM3 and the blue AIM4 (see Figs 8 and 9). Preliminary versions of both sets of data were presented in real-time on web sites at the Naval Research Laboratory and the Virginia Institute of Marine Science.

ACKNOWLEDGMENTS

Subsequent burial instrumented mines were built under funding from the Office of Naval Research (Roy Wilkins, Dawn Lavoie and Thomas Drake, program officers), the Naval Research Laboratory (program element N062435N), and under an SBIR contract administered by NAVSEA, (James Bloodsworth and William Kastner project managers). The Captain, Dan Nelson, and crew of the R/V Connecticut provided excellent seamanship during the deployment of the equipment. MVCO is ably managed by Janet Fredricks and Marguerite McElroy whose organizational talents were invaluable. Divers from NRL (Ricky Ray, Robert Fisher, Chad Vaughan, and Kevin Briggs) and WHOI (Glenn McDonald, Jay Sisson, Andy Girard, Peter Schultz, Fred Thwaites, and Erich Horgan) installed equipment on the seafloor and connected them to the communications and power ports at the MVCO node. Grant Bower, Conrad Kennedy, and Rick Mang helped prepare the instrumentation for deployment and provided logistical support during the experiments. This study was supported by the Office of Naval Research (Tom Drake and Brian Almquist, program officers). Peter Traykovski was also supported by an award from the Young Investigator Program of the Office of Naval Research. Michael Richardson was supported by the Office of Naval Research through Naval Research Laboratory Core funding under PE62435N. This is NRL contribution number NRL-PP-7430-04-0001.

References:

[1] M.D. Richardson and S.G. Tooma, "Environmental requirements to support mine countermeasure operation in shallow water," *U.S. Navy Journal of Underwater Acoustics,* vol. 43(3), pp.977-991, 1983.

[2] J. Edson, T. Austin, W. McGillis, M. Purcell, J. Ware, M. McElory, S. Hurst and C. Grant, "The Martha's Vineyard Coastal Observatory,". 6 pps.

[3] S. Griffin, J. Bradley and M.D. Richardson, "Improved subsequent burial instrumented mines". *Sea Technology* 44(11), pp. 40-44, 2003.

[4] P.D. Thorne and J. Taylor, "Acoustic Measurements of boundary Layer Flow and Sediment Flux", *J. Acoustic Soc. Am.* 108 (4), 2000.

[5] M.D. Richardson and P Traykovski, "Real-time observations of mine burial at the Martha's Vineyard Coastal Observatory" *Proceedings of the 5th International Symposium on Technology and the Mine Problem.* Naval Postgraduate School, Monterey, California, 22-25 May 2002, 11 pps. 2002.

[6] P. Traykovski, M.D. Richardson, J.A. Goff, L Mayer, R.H. Wilkens, and B. Gotowoka. Mine burial experiments at the Martha's Vineyard coastal Observatory. *Proceedings of the 6th International Symposium on Technology and the Mine Problem.* Naval Postgraduate School, Monterey, California, 9-13 May 2004.

[7] A. Trembanis, C.T. Friedrichs, M.D. Richardson, P. Howd and P. Traykovski. Real-time forcasts of scour burial at Indian Rocks Beach, Florida and Martha's Vineyard, Massachusetts. *Proceedings of the 6th International Symposium on Technology and the Mine Problem.* Naval Postgraduate School, Monterey, California, 9-13 May 2004.