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14. ABSTRACT

Over the past decade, high frequency acoustics, 0.5 MHz -5 MHz, has made significant contributions to the measurement of nearbed sediment processes. The capability of acoustics to provide co-located high temporal and spatial resolution profiles of the bed forms, the hydrodynamics, and the suspended sediments, is providing new insights into the interactions and feedback mechanisms of sediment transport. Acoustic instrumented mines, AIM's, were developed that could utilize this concept of acoustics, formulated for sediment studies, and apply it to scour burial. The AIM's were designed to measure not only the behavior of the mine, ie the roll, pitch, heading, and percentage burial, but also the near-field hydrodynamics, sediment movement and bedform changes, that cause the burial.

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UTILISATION OF THE APPLICATION OF HIGH FREQUENCY ACOUSTICS TO SEDIMENT PROCESSES FOR MINE BURIAL PREDICTION

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Over the past decade, high frequency acoustics, 0.5 MHz -5 MHz, has made significant contributions to the measurement of nearbed sediment processes. The capability of acoustics to provide co-located high temporal and spatial resolution profiles of the bed forms, the hydrodynamics, and the suspended sediments, is providing new insights into the interactions and feedback mechanisms of sediment transport. Acoustic instrumented mines, AIM's, were developed that could utilize this concept of acoustics, formulated for sediment studies, and apply it to scour burial. The AIM's were designed to measure not only the behavior of the mine, ie the roll, pitch, heading, and percentage burial, but also the near-field hydrodynamics, sediment movement and bedform changes, that cause the burial. The AIMs utilise 112 flush mounted acoustic transducers to measure percentage mine burial, expressed here as the surface area covered by sediment. By utilising the backscattered signal from a number of these transducers, sediment processes around the mine could be examined. This paper presents an analysis of backscattered signals collected during a deployment of the AIM's, within the Martha's Vineyard Coastal Observatory, between September 2003 and April 2004. Using the processed backscatter data in combination with pitch, roll, heading and pressure data, attempts are made to relate the hydrodynamic forcing conditions and sediment response, to the process of mine burial.

N.G.Pace and P Blondel, (Eds), Boundary Influences In High Frequency, Shallow Water Acoustics, Pages 375-382, University of Bath, UK 5th-9th September 2005

1 Introduction

Acoustics has been used for about two decades for the study of sediment transport processes [1]. Recent developments and integration of systems onto common platforms, has lead to acoustics providing detailed measurements of the hydrodynamics, suspended sediments and the bed morphology, within a common measuring volume. Such observations are providing fundamental information on the linkage and feedback between the flow, the sediment movement and the bedforms. In the present work advantage has been taken of this application of acoustics and it has been utilized in the study of mine burial processes, as part of the ONR Mine Burial Programme, MBP.

Acoustic Instrumented Mines, AIMs, were designed, developed and constructed as part of the MBP [2]. The AIMs were designed to measure the hydrodynamic processes, sediment movement, and bedforms close to the mine, in addition to the mine behavior of heading, roll, pitch, and percent burial, during burial. A total of 4 AIMs were built and have been used in mine burial experiments in the Gulf of Mexico and at the Martha's Vineyard Coastal Observatory. The AIMs are cylindrical in shape with a diameter of 0.5 m and a length of 2 m and have 112 acoustic transducers mounted on the surface the mines, which operate at 0.5 MHz, 1.5 MHz and 3.0 MHz. A number of the 1.5 MHz and 3.0 MHz transducers were used in a mode for measuring suspended sediment concentration around the mine and this is the focus of the present study. The AIM's utilise electronic compasses and 3-axis magnetometers and accelerometers to measure pitch, roll, and heading and have 6 pressure sensors to measure near bottom pressure fluctuations. These pressure data are used to determine a time history of significant wave height and period and, in conjunction with fixed mounted pressure sensors, determine mine burial relative to a fixed depth or the sediment water interface, if there are no major changes in the bedforms. A schematic of an AIM showing the acoustic beams is shown in figure 1, and figure 2 shows an AIM on the sea bed.

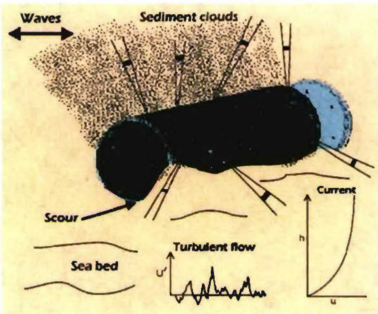

Figure 1. Schematic of an AIM showing the acoustic backscatter beams.

Figure 2. A picture of an AIM on the seabed.

The present work reports on the analysis of acoustic backscatter, ABS, data collected on the AIMs for suspended sediment measurements during a recent deployment at the Martha's Vineyard Coastal Observatory, MVCO. Two of the AIMs were deployed in 12 m of water on a fine sandy bed at approximately 25 m from the MVCO node during the period from September 2003 to April 2004. The layout is shown in figure 3. The Martha's Vineyard mine burial experiment was a large field campaign with a number of mine types deployed and numerous environmental measurements conducted [3]. A provisional inspection of the raw data showed some potential relationship between the significant wave height, H_s and the 3.0 MHz AIMs backscatter data, it was therefore considered interesting to analyse this data set in some detail first. Hydrodynamic parameters derived from the significant wave height and period were used to obtain the bed friction velocity, which with a criterion for suspended sediment entrainment, is used to interpret the temporal variations in suspended sediment concentration. The hydrodynamic and suspended sediment time series are used in a provisional way to interpret the motions of the AIMs.

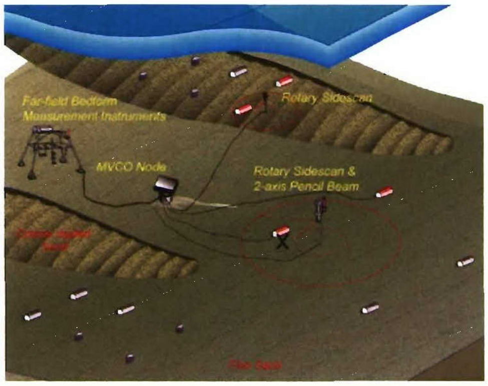

Figure 3. Layout of the experiment at the Martha's Vineyard Coastal Observatory. The AIMs are in red. X marks the AIM4 data analysed in this study

2 Background

2.1 *Suspension scattering*

For a suspension, insonified in the farfield of a piston source transceiver, the suspended sediment concentration, M, can be written as [1]

$$M = \left\{ \frac{V_{rms}\, r}{k_s k_t} \right\}^2 e^{4r\alpha} \tag{1}$$

$$\alpha = \alpha_w + \int_0^r \xi \, M dr$$

V_{rms} is the root-mean-square backscatter signal, r is the range from the transducer, k_s represents the backscattering properties of the sediment in suspension, k_t is a system constant, α_w is the sound attenuation due to water absorption and ξ is the sediment attenuation coefficient.

Since only one frequency, 3.0 MHz is analysed, knowledge of the size of the particles in suspension is required to evaluate equation (1). For the present work the value was not known, therefore an estimate for the suspended grain size was made from the size distribution of the bed sediments. A sensitivity test was carried out to examine the effect changing the particle size had on the acoustic inversion and this is described in section 3. As seen in equation (1), M also occurs on the RHS of the equation in the expression for the sediment attenuation. Therefore to evaluate equation (1) ξ was initially set to zero and the equation evaluated to obtain an initial estimate for M. This value for M was then used to evaluate the sediment attenuation and an improved value for M obtained. The process was repeated until a convergent solution was obtained.

2.2 *Sediment entrainment*

It was considered of use and interest to establish the threshold for suspending sediments at the mine location, and to compare the expected requirements for entrainment, with the observations of the suspended sediments collected with the ABS. A simple and often used criterion for suspending sediments is that the bed friction velocity, u_*, is greater than the settling velocity of the sediments in suspension, w_s [4]. In the present work a criterion of $1.2w_s$ was set. Using this requirement we have,

$$u_* \geq 1.2 w_s \tag{2}$$

w_s can be expressed as

$$w_s = \frac{\nu}{d_{50}} [(10.36^2 + 1.049 D_*^3)^{0.5} - 10.36] \tag{3}$$

$$D_* = \left[\frac{g(s-1)^{1/3}}{\nu^2}\right]^{1/3} d_{50}$$

Where g is the acceleration due to gravity, 9.81 ms^{-1}, s is the relative density of quartz sand to water, 2.65, d_{50} is the mean bed grain diameter in metres and ν is the kinematic viscosity of water and was taken to be $1.3.10^{-6}$ m^2s^{-1}. To calculate the bed friction velocity the following was used,

$$\begin{aligned} u_* &= \sqrt{f_w/2}\, U_w \\ U_w &= \frac{\pi H_s}{T_z \sinh(kh)} \\ f_w &= 0.237\left[\frac{k_s}{A_w}\right]^{0.52} \end{aligned} \tag{4}$$

f_w is the wave friction factor, U_w is the wave orbital velocity amplitude at the bed, T_z is the zero-crossing period of the waves, h is the water depth, k is the wave number of the waves, A_w is the orbital amplitude of the wave motion at the bed and k_s=2.5d_{50} is the Nikuradse equivalent grain roughness. Using k_s=2.5d_{50} for the calculation of the wave friction factor assumes the bed is nominally plane and there is limited ripple formation; this approximation may need further analysis.

3 Data Analysis

As mentioned above, to invert the 3.0 MHz data to obtain the suspended sediment concentration, M, an estimate for the suspended particulate size was determined from samples of sediments collected from the seabed. Figure 4 shows cumulative size distributions of the bed sediments.

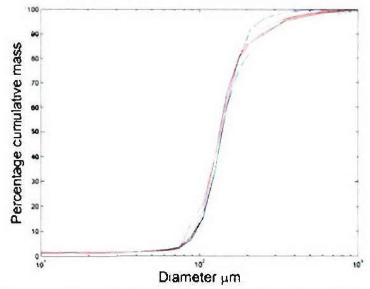

Figure 4 Cumulative size distribution, d_{50}=150 μm.

To assess the impact of particle size, figure 5 shows acoustic measurements of suspended sediment concentration using d_{50} = 100 μm -200 μm in the inversion. This range covers the greater part of the size distribution. Figure 5 shows very comparable magnitudes and temporal variation for the different particle sizes. The inversion was relatively insensitive to the particle size used and therefore the acoustic concentrations were considered to be reasonably robust.

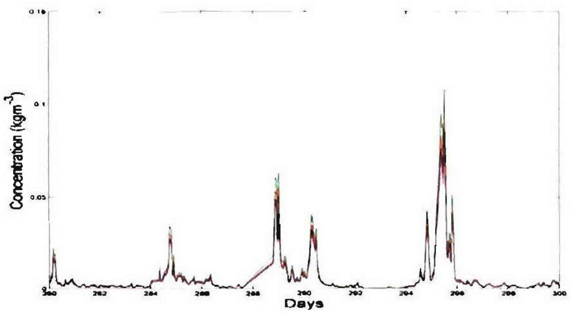

Figure 5. Acoustic measurements of suspended sediment concentration at 0.05 m from the AIM. d_{50} = 100 (—), 120 (—), 150 (—), 180 (—) and 200 (—) μm.

To examine the data sets that came from the AIMs, time series of M, u_*, H_s, T_z and roll were generated. An example from one of the 112 transducers, transducer 21, is shown in figure 6. One of the first points to note is the clear correlation between the ABS concentration time series and the friction velocity. Increases in u_* above the threshold velocity, 0.016 ms^{-1} show significant increases in suspended concentration. This relationship between u_* and M provides confidence in the veracity of the data set.

Examination of the time series for u_*, H_s, and M does provide a degree of explanation for the movement of the mine, represented here by the degree of roll. From figure 6 it can readily be seen that at the beginning of the record, days 270-295, there were high values of H_s and u_* with associated increase in suspended sediment. The increase in concentration of suspended sediment is coincident with scour around the mine. After sufficient scour, the mine began to pitch and eventually roll into its own scour depression, realigning the main axis of the mine with the dominate wave direction. At this point the mine was buried to a depth of 0.45 m relative to the sediment surface but with only 40% of the sensors covered as a large scour pit surrounded the mine. (See Figure 7) Between days 300-315, the values for u_*, H_s and suspended sediment concentration were relatively low and there was little or no scour and the mine did not move. Activity does pick up in u_* and H_s after day 315, however, the sediment suspended sediment concentrations remained relatively low suggesting that scour around the mine was less than during previous storms. It appears this activity was insufficient to create significant scour depressions around the mine and the mine remained static. The change in roll near day date 340 was caused by a repositioning of the mine. A large storm with significant wave heights close to 4 m occurred near day date 346, only 6 days after repositioning the mine. The significant increase in suspended sediment concentration at that time coincided with a significant roll of the mine of nearly 25 degrees. By the end of the storm nearly 80% of the mine's acoustic sensors were covered. The next two storms filled in the scour pit with a sand/mud mixture and the mine was nearly fully buried for the remainder of the experiment. Transducer 21 was the only backscatter sensor that was not completely covered during the rest of the experiment and provided backscattering from the water column. Though, even transducer 21 was apparently buried during parts of the experiment and the low values of suspended sediment concentrations beyond day 370 may reflect partial burial of the transducer by low density mud. The other transducers, which were buried, provided no analyzable data after day 370.

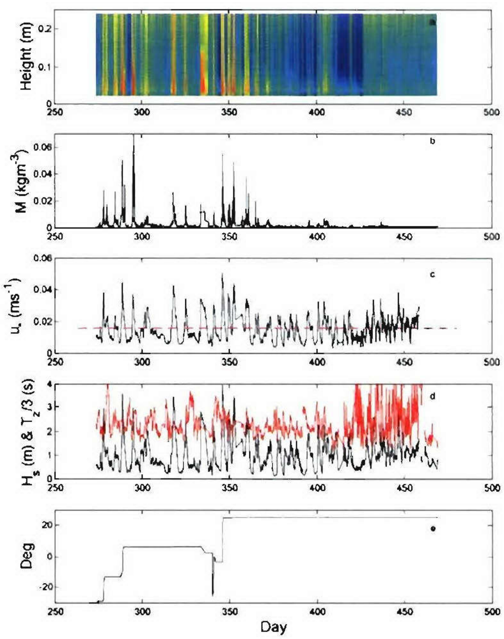

Figure 6. Plots of; a) the suspended sediment concentration within 0.25 m of AIM4 ABS transducer 21, b) the concentration at 0.05 m from the mine, c) the friction velocity (—) and suspension threshold velocity (--), d) significant wave height (—) and zero crossing period (—), and e) the roll of the mine. The time base is in days starting on Julian day 270, 27th September 2003 and concluding on day 470, Julian day 105, 14th April 2004. The mine was repositioned on day 340.

As shown in figure 3, as well as the acoustics on the AIMs, a 2-axis acoustic rotary pencil beam system was deployed close to the mine. This provided a measurement of the location of the mine and the seabed around it. An example of the data collected is given in figure 7. This shows the mine being partially buried prior to a storm that came through on the 22 October 2003, day 295. It is anticipated that the generation of such images, coupled with the AIMs hydrodynamics and sediment dynamics reported in this study, will provide data sets which will make a significant contribution to understanding the mine burial process.

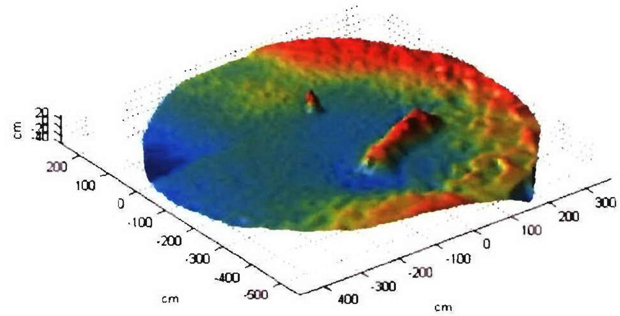

Figure 7. Measurement of the mine and the seabed on 21 October 2003, day 294, obtained using a 2-axis pencil beam rotary scanner. The mine is nearly flush with the surrounding sediment but has approximately only 40% of the acoustic sensors covered because of the extensive scour depression around the mine.

4 Conclusion

The AIMs were developed to measure not only mine behavior during scour burial, but also the hydrodynamic processes, waves, currents, and suspended sediments, responsible for that burial. This paper has focused on the measurement of the suspended sediments in the near-field of the mine and this was successfully extracted from the data collected. The suspended sediment variability has been compared with the hydrodynamic conditions and there was seen to be a direct correlation with the bed friction velocity. The movement of the mine has been linked to the hydrodynamic processes associated with scour burial. The coupling of the AIMs data with images from the rotary sector scan and pencil beam sonars should further aid the interpretation of the AIMs data and provide valuable information for modelling the mine burial process.

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