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14. ABSTRACT

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MEASUREMENTS OF SEDIMENT INTERFACE AND SUBBOTTOM PROPERTIES

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Abstract: *This paper describes a series of measurements of sediment properties during SAX04 and discusses the implications of these properties to sediment acoustics. Between September 20 and October 30, 2004 15 measurements were taken using IMP2, a sediment conductivity system developed to study sediment interface and subbottom properties. During this period, there were several weather events strongly influencing the sediment properties, ranging from Hurricane Ivan to a subsequent tropical storm. The IMP2 measurements clearly show the sediment ripple changes corresponding to the change of sea conditions. The large, non-symmetric ripples resulting from the hurricane decayed to a more symmetric form over time, while mud suspended in the water column was found trapped just beneath the interface. In between the weather events, biological activity on the bottom modified the bottom ripple features. Complementary cores were taken at the same sites where IMP2 was deployed, and cores confirmed the depth and location of the imbedded mud found by IMP2. Bottom roughness data were also taken at and near the IMP2 measurements using analog and digital stereo photography. These roughness measurements extend the IMP2 estimation of roughness power spectra to much higher spatial frequencies. [Work supported by the U.S. Office of Naval Research.]*

Keywords: *bottom, roughness, spectra, cores*

1. INTRODUCTION

This paper reports measurements of surficial sediments during SAX04 (Sediment Acoustics Experiment 2004), including roughness and subbottom heterogeneity. The scope and general description of the experiment can be found in papers on SAX04 in the same proceedings. The primary goal of this paper is to provide environmental data for acoustics models interacting with the bottom; the secondary goal is to provide direct measurements of bottom ripple fields for understanding and modelling such ripple fields. Most of the results are from data taken by the sediment conductivity system, IMP2, a description of which is given in [1]. The horizontal precision of IMP2 has been improved to less than 0.1 mm since the publication of [1]. During SAX04 the vertical step size was always set at 0.1 cm, and the horizontal step at 1 cm. Eight cores were taken at known locations immediately after IMP2 had taken data there. Corroborating results from stereo photography are also reported.

Between September 20 and October 30, 2004, when IMP2 took 8 sets of data, there were several weather systems going through the site, creating interesting characteristics of surficial sediments which have direct impact on sound waves interacting with the bottom. The locations of IMP2 deployments were within an area 50 m by 50 m around the moored R/V Seward Johnson at 17 m water depth; however, in this limited area, we observed both spatial and temporal variability. Within the IMP2 measurement area, acoustic systems were deployed and operated, measuring bottom forward scatter, backscatter, as well as bottom penetration spanning frequencies from 2 – 300 kHz. The reported results on surficial sediments should, to different degrees, support the modelling of the acoustic measurements. Because IMP2 provides a direct measurement of the sediment ripple field, its results offer a set of unique data to study sand ripple formation and evolution.

2. RIPPLE FIELDS OVER TIME

It has been found by various instruments and diver observations that major storms such as Hurricane Ivan and modest wind events like those that occurred after Ivan can form fresh sand ripples. Bottom currents and biological activity in and on the bottom, such as fish foraging, alter and modify the sand ripples over time. We find that over the observation period, in general the initially large, non-symmetric ripples resulting from the hurricane decayed steadily to a more symmetric form over time; its periodicity, while clearly noticeable, became more complicated and poorly defined. Fig. 1 shows sampled data on ripple fields over time. The left panel shows three 4-m long, one-dimensional ripple fields, one at the beginning, one in the middle, and one toward the end of the experiment. The top trace was measured five days after Hurricane Ivan passed to the west of the site. The ripples are asymmetric: high and sharply peaked on the top half and shallow and more rounded at the bottom half. In addition to the main period of about 75 cm, secondary, smaller peaks are apparent in between the main peaks. Over time, as the next two traces show, the ripple amplitude reduces and becomes poorly defined. The right panel shows the RMS height of ripple amplitude, indicating a clear steady decline over the measurement period. The ripple field should have a direct impact on sound penetration into sediment and bistatic scattering of sound from the bottom.

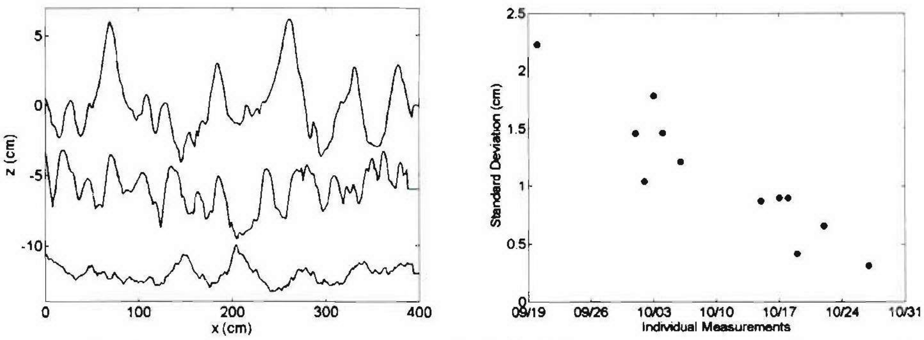

Fig.1. Left: Three ripple measurements each shifted 6 cm successively on the vertical axis. Right: The RMS ripple amplitude over time. The x-axis shows the date when data were taken.

3. MUD AND ITS EFFECTS

A result of Hurricane Ivan is that it caused a large amount of mud particle suspension in the water column, reducing the underwater visibility to almost zero. Subsequently, the mud was re-deposited on the bottom, covering part of the sand ripples. The coverage by mud was observed by several means to be patchy, but the mechanism for the patchiness remains unclear. IMP2 data (fig. 2) shows mud over-laying sand ripples. The left panel shows the measured formation factor, the ratio of the conductivity of water to that of a given medium. Sea water has the highest conductivity, followed by mud, then by sand. In the figure, the section with $x < 300$ cm has a layer of mud covering sand, while the last meter has no mud. In between the water/mud interface and mud/sand interface, there are trapped sands (orange). Cores 6-10 inches long were taken at known locations where IMP2 had taken data. The right panel in the figure is a core sample that clearly shows a dark layer of mud over lighter coloured sand. A sand inclusion within the mud is indicated by the red arrow. There were altogether eight cores taken, some from areas where IMP2 results show no mud coverage. In all cases, core results are consistent with IMP2 results in terms of the presence of mud and sand inclusions in mud. The cores have been preserved and further laboratory analysis is anticipated, including CAT-scans to obtain quantitative density and composition information.

The presence of a layer of mud on top of the sand ripples may have a profound effect on acoustics for certain frequency bands. Mud has a much smaller acoustic impedance and attenuation coefficient than sand, and hence is more acoustically transparent. One might expect that the effect of mud on acoustic scattering by sand ripples would be modest. However, the sand inclusions in the layer of mud will behave as suspended targets which may scatter strongly. Therefore, sand trapped in mud can greatly alter sound penetration into and scatter from sand ripples compared to the case without a mud layer. At very high frequencies (> 100 kHz), sound may not effectively penetrate through a mud layer; hence high frequency scatter from a mud covered bottom should be markedly different from that for exposed sand ripples.

Another effect of the mud layer is that it shields the sand ripples underneath from erosion from bottom currents and fish foraging. As a result, the large ripples formed after H. Ivan remained large under the protection of the mud layer. This suggests that for certain frequencies, acoustic scatter from a mud-covered area could be greater than that from an exposed area.

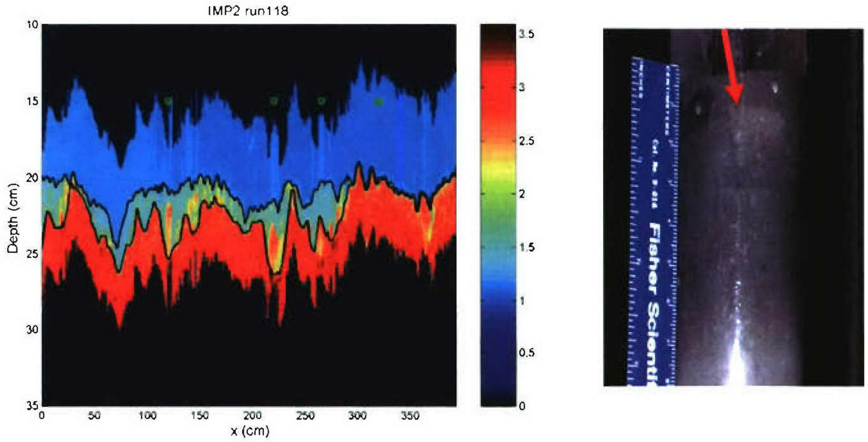

Fig.2. Left: Formation factor (color) for one of the IMP2 measurements. The light blue region is water, red is sand. The top black curve is the water/mud interface, the lower the mud/sand interface. In between the two curves is a region of mud with sand inclusions. The dark blue region on the top and bottom of the figure are regions with no data. The four green circles show the locations where cores into the sediments were taken. Right: core sample at x=265 cm showing sand trapped in the top mud layer as indicated by red arrow.

4. BOTTOM ROUGHNESS POWER SPECTRA

The power spectra of bottom roughness are presented in this section. In addition to IMP2 data, two kinds of stereo photography data will also be presented. One is an analogue system that has been used before extensively [2], the other is a digital stereo system recently developed. In both cases, the measurements were complicated by poor visibility caused by suspended particles in the water column. Only preliminary analysis on the stereo data has been performed; consequently spectra from data at very fine scales (2 mm and smaller) should be regarded as tentative. However, spectra at scales greater than 5 mm are of good quality and can be trusted. As a reminder, the IMP2 rough interface data are sampled at 1 cm intervals.

The one-dimensional power spectra are all obtained from windowed periodograms and are summarized in Fig. 3. The spectrum from IMP2 is an average of 12 individual measurements, the one from the analogue stereo system is an average of 3, and the one from the digital stereo system is from a single measurement. Each of the IMP2 surface profiles is about 4 m in length, long enough to provide spectral peaks from dominant ripple wavelengths. However, as shown in the figure, while the low-wavenumber part of the spectrum has a broad maximum, it does not show a narrow peak, indicating a lack of a single dominant ripple wavelength. This is consistent with the observation given in Fig. 1 that while the ripple fields are present throughout the experiment period, the ripple wavelength varied from location to location and from time to time. A particular example is given in Fig. 4. This is a unique and important ripple measurement because it is the only measurement inside the SAX04 buried target field where backscatter and bistatic scatter experiments were conducted. It can be seen that within the four meter length, the ripples show varied wavelengths, ranging from 20 to 75 cm.

Going back to the power spectra in Fig. 3, we find that between wavenumbers 0.1/cm – 2/cm, where all three kinds of data overlap, the power spectra are roughly consistent with one another but with some noticeable variation. A least square fit in this wavenumber region to a power-law spectrum gives the following numerical results: the one-dimensional power-law exponent $\gamma_1 = 2.82$, and the power-law strength $w_1 = 0.0061\ \mathrm{cm}^{3-\gamma_1}$. The parameters for the equivalent two-dimensional power-law spectrum are $\gamma_2 = 3.82$, $w_2 = 0.0038\ \mathrm{cm}^{4-\gamma_2}$. The two-dimensional strength expressed in meter unites is $w_{2m} = 0.00166\ \mathrm{m}^{4-\gamma_2}$. For reference, the power-law fit to all SAX99 roughness data is also plotted in the figure (truncated at the maximum wavenumber measured by IMP2 during SAX04).

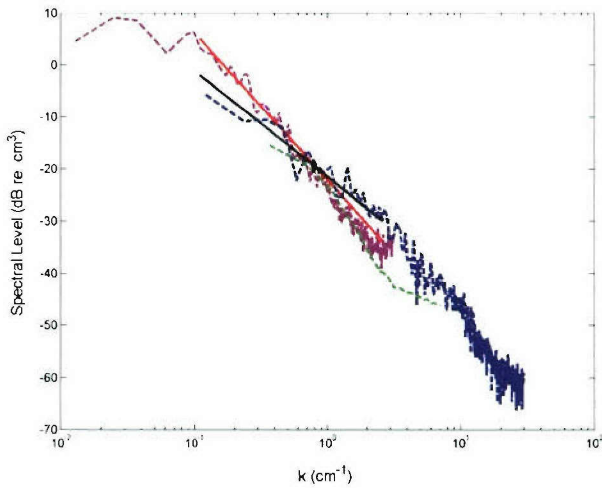

Fig.3: Power spectra derived from IMP2 (pink) and a power-law fit (red), from digital stereo photography (green), and from analogue stereo photography (blue). The black line is the power-law fit to SAX99 roughness spectra.

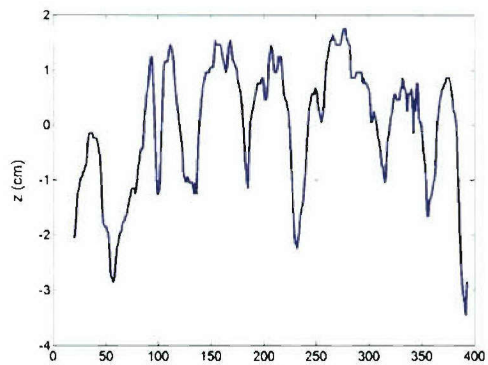

Fig.4: Ripple field measured inside the buried target field.

To understand the variability of the power spectra, we consider the confidence bounds of the estimates. First, assume that all IMP2 measurements are mutually independent and are from a statistically homogeneous pool. With that assumption, the 95% confidence bounds for the average spectrum are tightly bunched together, as shown by the two black lines in Fig. 5. A close examination, however, indicates that the spectra are much more varied due to spatial inhomogeneity. Half of all the IMP2 data fall into two groups of measurements, each consisting of three measurements within 4 m from one another. Because the measurements are so close to each other within each group, we assume that ripple surfaces from each group are from a statistically homogeneous pool. Thus, we obtain two sets of bounds for the two groups. These are also shown in Fig. 5. Note that the bounds of the two groups do not overlap with each other, suggesting that the ripple surfaces are spatially inhomogeneous. A similar conclusion was also reached for SAX99 data [3]. The implication of this is that when modelling acoustic scattering from ripple fields, it is important to use spectra derived from ripple measured over the same area where acoustic data were taken.

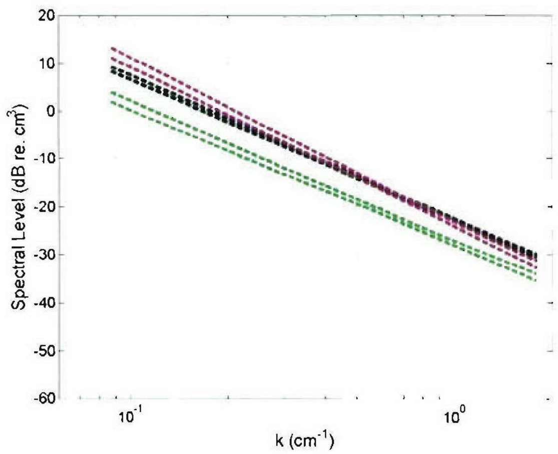

Fig. 5: 95% confidence bounds of power-law spectra. The black lines are bounds assuming all IMP2 measurements are from a statistically homogeneous pool. The pink and green bounds are obtained from two sub-groups of surfaces, each consisting of three.

5. BIOLOGICAL REWORKING

One interesting feature of the rough interface is its modification at fine-scales by biology, possibly by fish. In general, foraging on the bottom by fish will contribute to a gradual reduction over time of the ripples formed by weather events. An added twist in the SAX04 ripple field is the introduction of the mud layer. Without the mud layer, all ripples would be eroded more or less equally by effects of currents, waves, and biology on the bottom. However, when a layer of mud covers up freshly formed ripples, the ripples are sheltered from alteration from above. Only ripples in areas without over-laying mud will be exposed to erosion. The left panel of Fig. 2 is a good example of these effects, and the water/mud and mud/sand interfaces from Fig. 2 are plotted in the left panel of Fig. 6. This is a case where mud fills in the troughs of the ripple fields and the ripples underneath are protected. As seen in the figure, the mud/sand interface is smoother, whereas the water/mud interface is rougher at small scales. At the right most quarter of the surface where there is little mud, the sand surface has the same fine-scale features as the mud surface does elsewhere. A closer examination of the fine-scale features of the rough surface shows that the wavelengths are all between 2 cm and 7 cm. These observations suggest that the fine-scale features are results from alteration from activities above the bottom, most likely from fish foraging on the bottom.

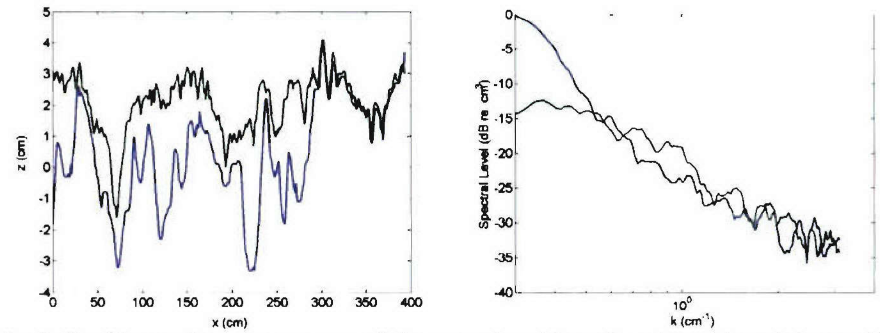

Fig.6: Profiles and power spectra of the water/mud interface (green) and the mud/sand interface (blue). Notice the small wavenumber region between k = 0.7/cm and 1/cm where the spectral level of the mud interface is a few dB higher than that of the sand interface.

The right panel of Fig. 6 shows the comparison of the power spectra from the two interfaces. While the sand interface has higher spectral level at low wavenumbers, the spectrum of the mud interface is higher by several dB owing to its higher fine-scale roughness. The higher spectral level for the mud interface is most likely due to fish activity at the water-mud interface. The sand interface under the mud is more sheltered from this roughness producing mechanism.

It is interesting to anticipate the impact on acoustics of the mud layer and biological alteration of the ripple fields. We might expect that enhanced sound penetration into a rippled sand bottom and target detection is in some cases aided by the presence of a mud layer overlying sand ripples. This expectation is based on the following observations: (1) the mud layer tends to preserve the high amplitude of the ripples, (2) the mud layer has only minor refractive and attenuative effects on the incident sound, (3) mud backscattering levels are lower than for sand, and (4) backscattering levels from fine-scale roughness on sand may be suppressed for a sand interface under the mud owing to the suppression of fine-scale roughness. The last two items may account for reduced backscatter from the bottom, thus increasing the signal-to-noise ratio for buried target detection. This expectation, however, may turn out to be overly optimistic, since sand inclusions might also sometimes occur in the mud layer, increasing backscattering levels. Clearly, further work will be required to unravel these competing effects.

6. ACKNOWLEDGEMENTS

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