Temporal Fluctuations in the Acoustic Scattering from Bottom-Deployed Objects and Localized Biological Treatments

Kevin L. Williams
Applied Physics Laboratory
University of Washington
Seattle, WA 98105
phone: (206) 543-3949 fax: (206) 543-6784 email: williams@apl.washington.edu
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LONG-TERM GOAL

My long term goal is to understand, for different environments, the biological and hydrodynamic processes important to the changes seen in the acoustic scattering from ocean sediments and from proud and buried mines as a function of time after deployment.

OBJECTIVES

My objective in this effort is to process and interpret acoustic monitoring data taken on both mine shapes and localized biological treatments during the 1995 ORCAS experiment. The ORCAS data allows examination of the acoustic scattering from mines and biological treatments for up to two months. Four types of results can be produced using the data: backscattering, scan-to-scan decorrelation, cumulative decorrelation relative to a reference scan, and bathymetry. The goal is to examine the results in combination to quantify, interpret, and guide future research on the temporal variations of scattering from bottom deployed mines. Of particular interest to me are the temporal variations of scattering from buried objects.

APPROACH

Objects placed on or near the ocean bottom can be expected to alter the behavior of the benthic community in the immediate area. This same biological activity holds the potential of altering the acoustic returns from the objects. This simple premise, in part, motivated the experiment and analysis presented here. In addition, the general use of acoustics as a remote sensing tool for monitoring biological activity has been a subject of study for quite some time. Results from previous work [1-5] implied a need to carry out ground truth experiments where localized biological treatments were carried out and monitored acoustically over a period of weeks.

Data on mine-like objects and localized biological treatments were acquired by the Benthic Acoustic Measurement System (BAMS) [1-6] as part of the ORCAS experiment. BAMS operates at 40 and 300 kHz, and acquires acoustic backscattering data from a circular region of about 50 meters radius. The array apertures are divided into upper and lower halves to allow interferometric measurement of sea-bed bathymetry. Digitization and signal generation are controlled by a single clock, making it possible to make sensitive phase comparisons between echoes acquired in separate scans, even when the scans are

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separated by times on the order of weeks. Such phase-coherent processing can be used to observe small changes in the sea bed.

My approach has been to concentrate on the BAMS 40 kHz data since 40 kHz penetrates further into ocean sediments than 300 kHz and since the 300 kHz data has been exploited more fully by A'Hearn et.al. [5] than has the 40 kHz data. However, in examining localized biological treatments I have used the 300 kHz data to pinpoint the location of the treatment since the 300 kHz sonar has higher spatial resolution than the 40 kHz sonar. The general approach has been to form four different types of images from the data (scattering strength, bathymetry, scan-to-scan decorrelation, cumulative decorrelation) and use them to determine which pixels to examine further. The temporal variation in scattering, bathymetry and correlation for those pixels were then more closely examined and compared to one another.

WORK COMPLETED

Images [3] (scattering, bathymetry, and correlation) were first formed of all 585 scans at 40 kHz and all 62 scans at 300 kHz acquired during the 2 month deployment. Further processing involved forming similar images in the immediate vicinity of each object or treatment. Constructing movies of these images then allowed a better qualitative assessment of time variations and were used to determine the pixel or pixels to examine quantitatively via plots of its scattering, bathymetry, and correlation values as a function of time. The only treatments examined at 40 kHz were those also observable in the 300 kHz images, i. e., bait, Acilla, and cockle treatments [5]. A manuscript detailing the experiment, processing, and results has been submitted to the IEEE Journal of Oceanic Engineering (see Publications section).

RESULTS

Figure 1a shows the time variation in the Lambert parameter (indicative of scattering strength), bathymetry relative to the base of the tower, incremental decorrelation, and cumulative decorrelation for three undisturbed control sites and for three spheres: a volume sphere tethered above the interface, a proud sphere placed on the water-sediment interface, and a sphere buried into the sediment by divers.The general behavior of the three control sites (solid curves) is similar. That is the Lambert parameter is in the range of -20 to -25 dB, the scattering looks to be coming from slightly above to 50 cm below the vertical location of the feet of the tower which is identified as the water-sediment interface, the incremental correlation stays high, and the cumulative correlation decreases to between 0.75 and 0.9 over the 10 days (100 scans) plotted. The fact that the scattering at times seems to be coming from slightly above the interface is most likely due to a small bias error due to the tower feet sinking slightly into the soft sediment. The fact that scattering at times appears to come from well below the interface is consistent with the scattering being due to volume inhomogeneities within the sediment.

The volume sphere has a high scattering strength (Lambert parameter), is tethered well off the bottom, moves significantly from one scan to the next (the incremental correlation is much lower than for any of the other sites in Fig. 1), but there is little permanent change (indicated by the fact that the incremental and cumulative correlation coefficient values are of the same magnitude). The proud sphere (dashed curve) has a lower scattering signature than the volume sphere but still very high relative to the control sites. The scattering appears to be coming from about 50 cm above the water-sediment interface, and the level of activity, as indicated by the incremental and cumulative decorrelations is about the same as the control sites.

The buried sphere (dotted line) part of the experiment was performed with the goal of examining how its signature changed with time after burial for the relatively low resolution 40 khz sonar. The buried sphere was first placed on the bottom. Connected to it was a 10 ft. length of pipe with a small float at the top. The pipe was used to aid in burial. The next day the sphere was buried and the pipe was removed. The Lambert parameter and bathymetry reflect this scenario. The first ten scans show that the proud and buried sphere scattering was about the same. The bathymetry during these scans indicate the presence of the 10 ft. pipe and float. Upon burial and removal of the pipe the bathymetry indicates that scattering is coming from near the sediment-water interface (starting near scan 11). The scattering strength drops a few decibels when the sphere is buried and pipe removed but is still at least 10 dB above the level at the control sites. The next two days (20 scans) proves very interesting. Over that time the scattering from the buried sphere continues to decrease so that by the time scan 30 is reached the scattering level at the buried sphere location is the same as at the control sites. Furthermore, even though the scattering strength stabilizes at that point, the cumulative decorrelation indicates that permanent changes are continuing throughout the rest of the time period shown. In particular, by the end of the time period of the figure the cumulative correlation coefficient has dropped to about 0.4.

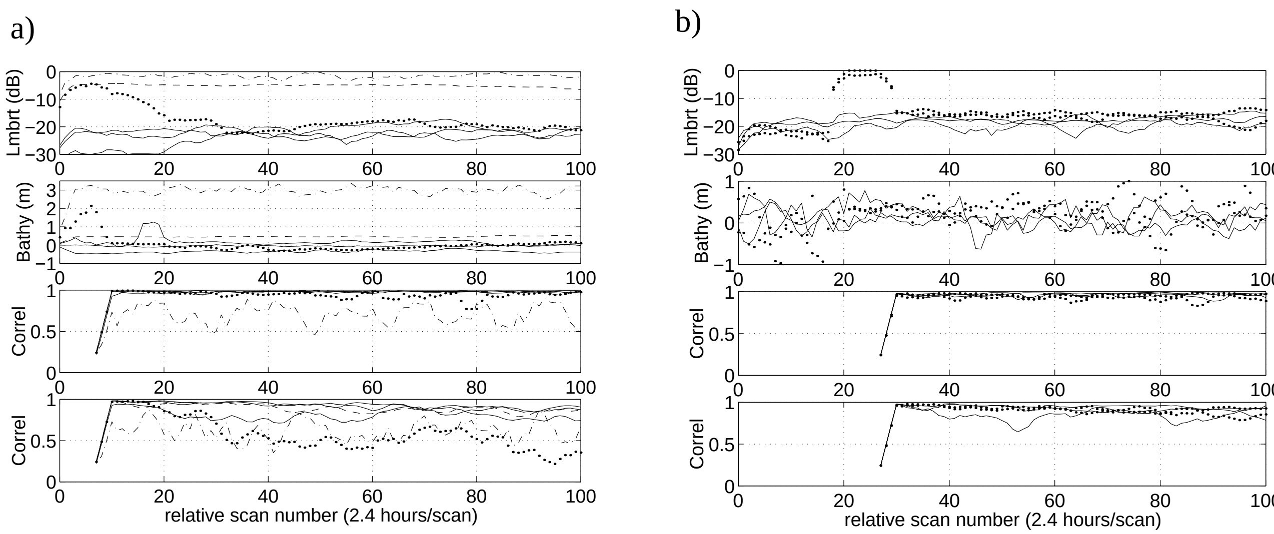

Figure 1. The results for four types of processing are shown: a) for a volume sphere (dash-dot), proud sphere (dash), buried sphere (dotted), and three control sites at 20 m range (solid), b) for two bait treatment sites (dotted) and three control sites at 30 m range (solid). From top to bottom; Lambert parameter, bathymetry relative to the base of the tower, scan-to-scan incremental correlation coefficient, scan-to-reference scan cumulative correlation coefficient.The horizontal axis for all plots is time (in number of scans) relative to an initial scan chosen separately for each object and site. In the case of the spheres and the control sites the choice was based on when the sphere was first introduced into the environment by divers. For the biological treatments, where a marker sphere was put down for one day and then the treatment carried out and the marker sphere removed, the initial scan chosen for the Lambert and bathymetry plots was 20 scans before the one in which the marker sphere was introduced. The correlation calculations start with the first scan after divers had finished all activity in the area and thus start after the scattering strength and bathymetry plots.The curves have been smoothed by using a four scan sliding average. Thus the transient behavior in the first four scans is artificial and should be ignored.

The cumulative decorrelation rates for undisturbed regions in the ORCAS experiment have been used in a biological diffusion model [4] to quantify biological reworking or “activity level”. The cumulative correlation shown there is consistent with that shown in the control sites by the end of the 10 day period, i.e., the activity level is similar. The much higher cumulative decorrelation rate of the sphere (the correlation coefficient reduces to about 0.4 in the time the undisturbed sites reduce to about 0.8) indicates that the activity level in the region of the buried sphere is much higher. This implies that if activity levels from undisturbed sediment were used to predict the rate at which the sphere would be “incorporated” into the environment a large error would result. Qualitatively, this result (increased activity near the sphere) is perhaps to be expected. Biological activity is well known to be enhanced at interfaces. However, the ability to quantify the increased activity is an unique aspect of the data taken at ORCAS. Reference 4 shows that decorrelation to a correlation coefficient of 0.5 in the natural ORCAS environment takes longer than the 58 days of the experiment whereas this correlation coefficient value (0.5) is reached in a little over three days for the buried sphere site. The prevalent benthic biota seen in the ORCAS area are mysids [7] and it is reasonable to assume that they are responsible for the activity seen in the data. Obviously, more extensive monitoring near the buried sphere should be included as part of any further experiments.

Figure 1b compares the results at two of the bait sites (dotted curves) with control sites (solid curves). The third bait site was near the range where air-water surface contamination began to be obvious in images formed and is therefore not shown. In the top panel, the first 18 scans for the bait sites show Lambert parameter values before insertion of any bait treatment and the next 12 scans show large Lambert parameter values due to the marker spheres placed at each site the day before biological treatments. The scattering strength curves after the bait is inserted are biased above both the control curves and the pretreatment levels. Most of the post-treatment bathymetry data for the bait sites shows the scattering coming from above the water-sediment interface, sometimes as much as a meter above. Also, the bathymetry becomes more variable with time after treatment.The scan-to-scan decorrelations of the bait are at times higher than for the control sites. Even so, the cumulative decorrelation rates at the bait sites are similar to those of the control sites. The reason for the increased scan-to-scan decorrelation at the bait site cannot be unambiguously determined in this experiment but it is hypothesized to be near-bottom fishes and crabs exploring the bait. This would lead to increased scan-to-scan decorrelation but would not affect the cumulative rate since the main reason for the long-term cumulative decorrelation is attributed to changes within the sediment. This hypothesis is also consistent with the bathymetry results indicating scattering coming from above the interface that becomes more variable with increased time after treatment. This increased variability is interpreted as due to increased numbers of in-volume feeders as time progresses. The fact that the Lambert parameter is high immediately after the treatment, and remains high, is interpreted as indicating that the bait/rebar combination contributes significantly to the scattering. Thus the total scattering after the treatment is due to both the bait-rebar combination and volume scattering from organisms feeding on the bait. The scattering from the bait-rebar dominates the Lambert results, but the more sensitive phase measurements inherent in the bathymetry results detect the presence of the feeding organisms. This same type of signature could also result if an object placed on the bottom acted as a refuge for fish.

IMPACT/APPLICATION

Combining the information obtainable from relatively simple transducer arrangements provides a novel way of examining the benthic environment. The results on the man-made objects demonstrate that, when used in combination, the different types of images allow easy determination of the vertical location of the object as classified into volume, proud, or buried. The scattering strength alone does not allow this discrimination but the bathymetric information has high enough resolution that it easily discriminates a proud object from a buried one. Furthermore, the increased ping-to-ping decorrelation is a robust discrimination of a volume mine from a proud or buried one even in the absence of bathymetric information. The possibility of increased activity near proud and buried objects should be taken into account if monitoring of operational areas are to be carried out.

The results for the bait treatments again indicate the utility of multiple types of processing being examined at the same time. In proceeding in this manner it was possible to see both increased scattering level (via the Lambert plots) due to the introduction of a man-made object (bait/rebar) and increased localized activity near, but not in, the bottom (via the correlation and bathymetry plots).

TRANSITIONS

RELATED PROJECTS

This work has motivated a continued effort along the same lines in the upcoming "High Frequency sound interaction in ocean sediments" Departmental Research Initiative (DRI).

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