Shallow Water Data Collection System

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Abstract - **In September 1991, the first of a series of measurements was made with high frequency (≥ 10 kHz) sonar in shallow waters (35-55 m) of Block Island Sound. Approximately 250 sonar echoes were collected with sonar heads mounted on a remotely controlled, submersed system towed by a surface ship over various bottom types. For ten types of transmit waveform, the output from each transducer in the sonars' (8x8) arrays was individually recorded digitally. Concurrent oceanographic and geologic measurements included vertical and horizontal profiles of conductivity, temperature, and depth (CTD); current; wave height spectra of the sea-surface; side scan sonar mapping and stereo photography of the bottom; ambient noise; bottom cores; underwater video. Air-filled steel spheres were moored at the site as a distributed target for acoustic imaging experiments. Moreover, data have been analyzed to characterize boundary reverberation for two cases representative of the variability encountered during the experiment.**

I. INTRODUCTION

Recent interest in diverse shallow water areas has led to concentrated study of their unique acoustical and oceanographic properties. Accordingly, an experimental system was developed to investigate high frequency acoustics for application to sonar operations in shallow water. Furthermore, various shallow water sites have been selected for experiments with high frequency sonars mounted on a submersed platform towed by a surface ship. The frequency range and water depth of interest are 10-100 kHz and ≤100 m, respectively. Supporting the measurement of sonar performance, comprehensive environmental measurements were also taken. The first experiment was conducted in September 1991 at a shallow water test site approximately 3.5 km south of the eastern edge of Fisher's Island in Block Island Sound. The site is a 2 km x 4 km rectangle centered at 41° 15′ N 71° 56′ 24″ W on the eastern U. S. continental shelf with bottom depths of 35-55 m. The experimental setup is illustrated in figure 1. Approximately 250 sonar echoes were collected over three days using several high frequency sonar heads on the platform, which was towed by the R/V Onrust, an 18-meter research vessel. Measurements were taken over various bottom materials: cobbles, gravel, shell, and sand. Ten transmit waveform types were used including cw pulses and fm coded pulses. The output from each transducer in the (8x8) sonar arrays was individually recorded digitally on 5 inch optical discs. Recording space-time samples in this way (as opposed to recording only preformed beam outputs, for example) is necessary for high resolution, three-dimensional imaging of targets and boundaries in shallow water. High speed data acquisition and signal processing technology is applied to preserve the integrity of the acoustic data for coherent spatial processing. This paper summarizes the experiment including a description of the instrumentation, measurements, signal processing, and examples of preliminary findings regarding acoustic imaging and reverberation in shallow water.

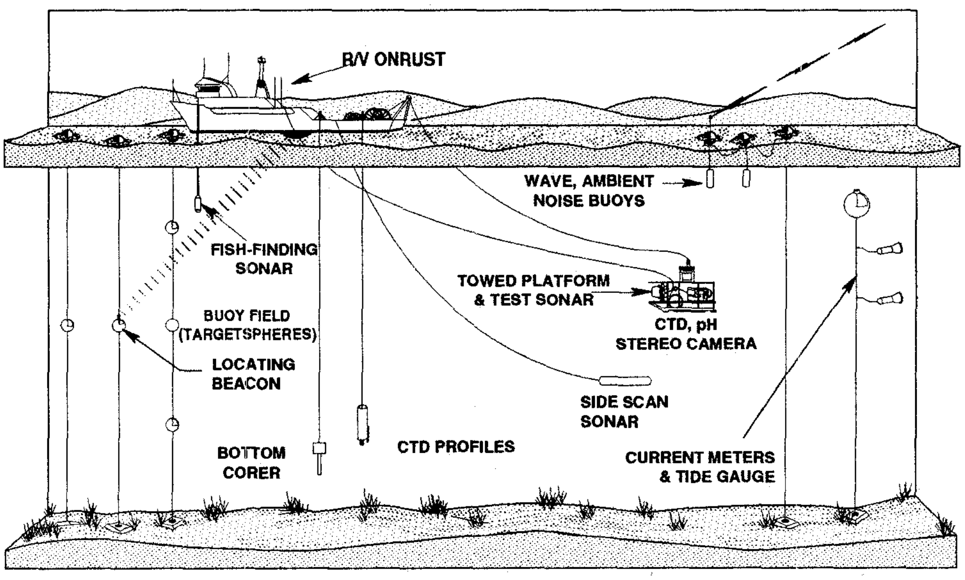


Fig. 1. Experimental setup.

II. INSTRUMENTATION AND MEASUREMENTS

The instrumentation consists of shipboard data acquisition and analysis subsystems, integrated navigation components, oceanographic sensors, and a modified sonar head mounted on the towed platform (figures 2 and 3). The complete system can be deployed from a small ship like a trawler and transported in standard air shipping containers. The acoustic analog data are transmitted from the instrumented sonar head over cable to the host ship for signal conditioning, processing, and recording. The sonar heads are remotely controlled from topside for both pan and tilt with custom gimbals (±90° horizontal; ±30° vertical) for several sizes of sonar heads (≤ .5 m dia.). The platform (the TSS-1000 from Deep Sea Systems, Inc.) operates in sea state 3, to an operational depth of 120 m, and at speeds to 1.5 m/s. Data from GPS and acoustic transponders (mounted on ship, target, and towed platform) were integrated by computer for precise navigation and tracking. The sonar heads were modified to provide individual transducer output voltage, preamplified and differentially driven with a variable gain (10-40 dB) remotely selectable aboard ship. All 64 analog signals are transmitted to the shipboard electronics over a 500 feet long (1 inch dia.) data cable, with two additional cables for power and control. Each of the 64 channels contains a differential amplifier/filter; an analog signal conditioner (72 dB programmable gain and an anti-aliasing filter with bandwidth programmable from 1-150 kHz); a digital data acquisition processor with a sampling rate to 1 mHz (12 bit/sample), a programmable digital filter, and random access buffer memory (0.5 mbyte). Figure 4 shows some of the settings used for the September 1991 experiment. Among all channels, gain and phase match to within 0.1 dB and 1°, respectively. Ten types of waveforms, designed for imaging and scattering function estimation, were transmitted: cw, linear stepped fm, and various hopped-frequency codes; duration and bandwidth range from 2-560 ms and 4-2000 Hz, respectively. Horizontal and vertical transmit beam patterns were selectable from beamwidths of 15°- 60°.

Environmental data include vertical and horizontal samples of sound speed, directional surface waves, near-surface ambient noise, current speed and direction, tidal height, and bottom geoacoustic characteristics (figure 1). Vertical sound speed profiles were measured within 1 hr of sonar measurements, deployments alternating with acoustic pings (figure 5). The geological data were obtained immediately after the acoustic tests. Sound speed variability was determined using two Seabird self-recording CTD instruments: a Seacat, deployed from the R/V Onrust, for the vertical profiles and a Sealogger, on the TSS-1000, for the continuous horizontal profiles. A comparison of synoptic sound speed measurements made within several meters at the towed platform depth shows that the two instruments agree to within ± 0.07 m/s. During the experiment, the principal cause of vertical variability in sound speed was the onset of the late summer-fall water column transition brought on by storms (e. g., the evolution of cooler, fresher water, especially in the near-surface layer). This seasonal transition is evidenced in

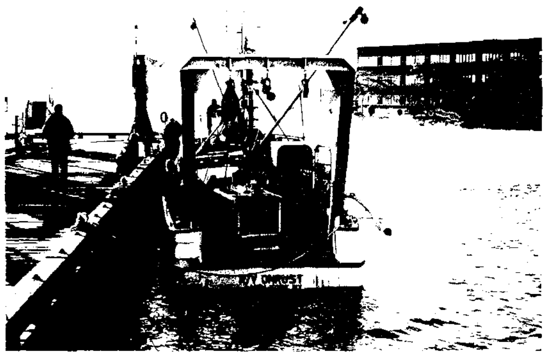


Fig. 2. Towed platform on R/V Onrust.

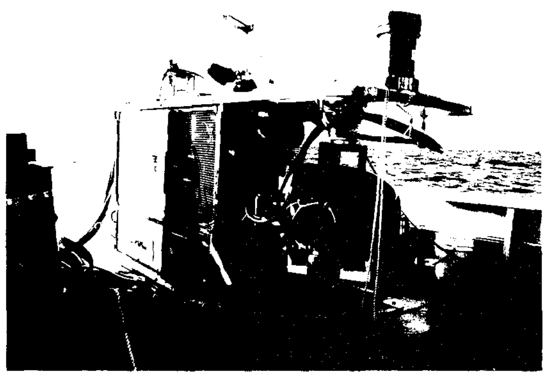


Fig. 3. Towed platform with sonar head.

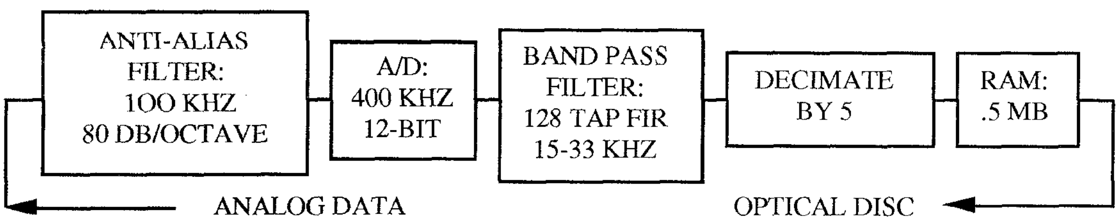


Fig. 4. Data acquisition system for each of 64 channels.

vertical sound speed profiles from 24 and 28 September 1991, designated as ssp(a) and ssp(b), respectively (figure 6); these are used in the comparisons of modeled and measured reverberation shown subsequently. Within the site, horizontal variability in the sound speed field at the source depth was estimated to be approximately 0.5 m/s. Bottom morphology was determined with a 100 kHz EG&G side scan sonar and a Photosea M2000 stereo camera. Sediment layers in the upper 1.5 m of the bottom were determined from six gravity cores, which, after preliminary analysis, indicate sand, shells, gravel, and cobbles. Measurements of directional wind waves were made with an Endeco 956 wave rider buoy tethered to a surface mooring (figure 1); data were telemetered to shore 22 km from the site. Synoptic wind and sea state observations were also made from the R/V Onrust; significant wave height was 0.2-2.6 m.

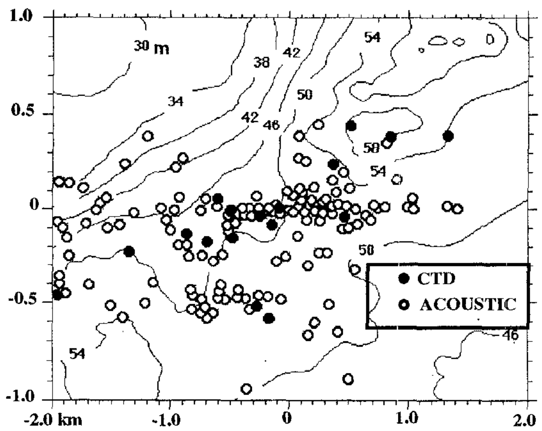


Fig. 5. Sonar and CTD measurements.

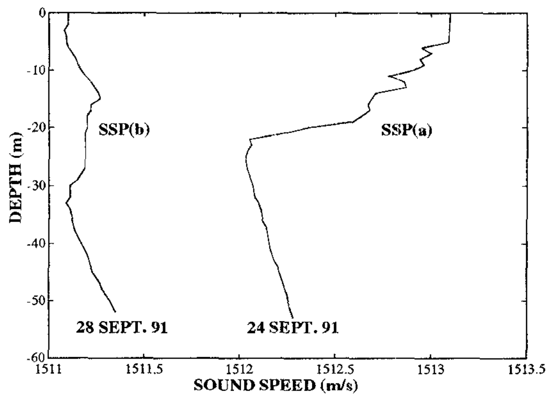


Fig. 6. Vertical profiles of sound speed.

III. ACOUSTIC IMAGING

For temporal signal processing in the laboratory, the digital data are bandpass filtered, and analytic signals are generated and matched filtered for each of the 64 channels. Then spatial processing (time delay and sum beamforming) is performed to generate acoustic images of the water column. Multiple beams are formed simultaneously in azimuth and elevation at increments of 1/6 of the null-to-null beamwidth of approximately 29° (for the four-wavelength aperture of the arrays used) - an interpolation that is finer than conventional Rayleigh spacing and produces more detailed acoustic images [1]. Figure 7 shows the setup of the five spheres (air-filled, 30 inch diameter, .5 inch steel) in the experiment and the orientation of the sonar's transmit beam pattern, which has side lobes ensonifying both the surface and the bottom. (The spheres were moored at the origin in figure 5). The main beam ensonifies only the three spheres in the middle of the water column. Figure 8 is an example of an acoustic image of the spheres using a 2 ms cw pulse. Receive beams are formed at 5° increments between ±90° in azimuth and elevation (37^2 beams)

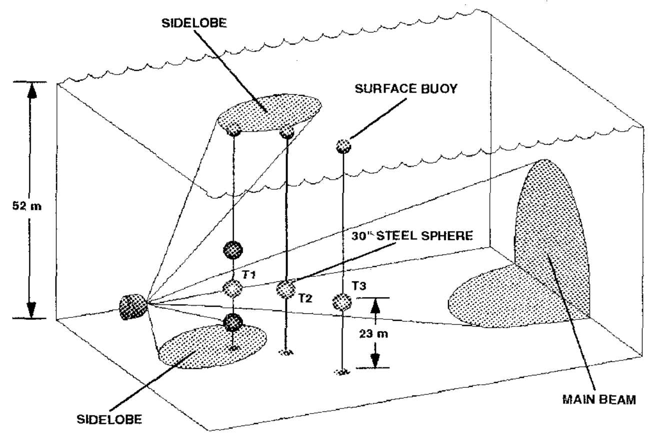


Fig. 7. Arrangement of acoustic targets.

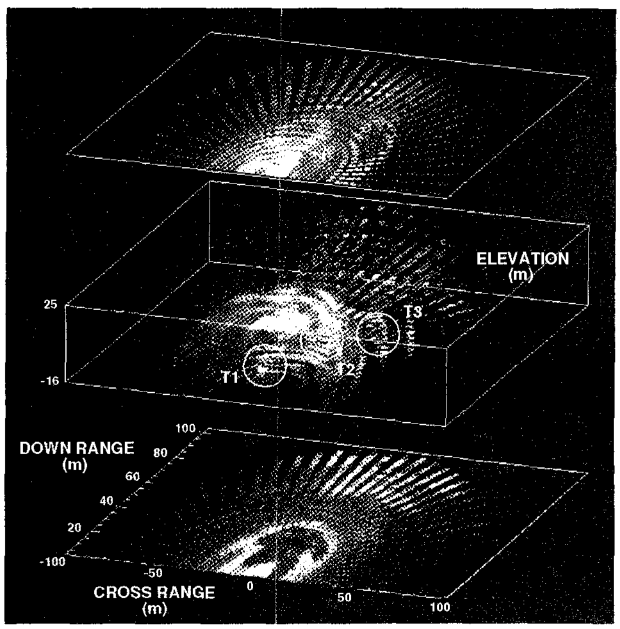


Fig. 8. Acoustic image of spheres.

IV. REVERBERATION

Figure 9 shows two temporal records of measured reverberation level (instantaneous power) for a cw pulse of 85 ms duration: one from a single (arbitrary) transducer, another the (incoherent) average of the individual time series from all transducers (52 in this case) in the array. Although the time series are not necessarily statistically independent, the spatial average clearly reduces the variance of the estimate of the reverberation level, demonstrating the advantage of multichannel recording. This advantage is further demonstrated by of a comparison between measurement (spatial averaging with further temporal averaging for 42 ms) and results from the Generic Sonar Model (GSM) [2]. For backscattering and forward scattering from both the sea-surface and the bottom, the GSM was augmented by various models as compiled and extended by the Applied Research Laboratory, University of Washington [3-6]. Two cases representative of the variability observed in the experiment were analyzed: (a) a downward refracting sound speed profile ssp(a) with wind speed of 1.4 m/s; (b) an upward refracting profile ssp(b) with wind speed of 4.1 m/s. The in-band ambient noise (including the ship's contribution), measured by the sonar itself, was about 80 dB // μPa and insignificant. In both cases, water depth is 50 m; source depth is 25 m; from analysis of core material, the surface sediment on the bottom is sand and nonuniformly distributed shells. In the model, only medium sand is assumed, the shells' contribution undetermined. The waveform is the aforementioned cw pulse of 85 ms duration. In case (b), the results are consistent with predominance (after about 0.3 s) of surface effects, particularly, backscattering and forward reflection losses due to bubble layers; however, in case(a), where agreement between model and measurement is poor, bottom scattering is probably predominant. This conjecture is consistent with the representation in figure 10 of reverberation intensity $I_r(\theta, t)$ versus vertical receive angle θ and time t, attained by forming vertical beams over $\pm 90°$ at 3° increments and displaying, in logarithmic gray level,

$$\{i_r(\theta, t) = I_r(\theta, t)/\max_\theta I_r(\theta, t): i_r(\bullet) \geq .9, \text{ for all } \theta, t\})$$

The distinct bands evident in the measured levels correlate well with the significant eigenrays, corresponding to sea-surface and bottom sources, calculated from the GSM [2]. This reveals, in case(a), the aforementioned predominance of the bottom-induced effects.

V. SUMMARY

A portable system for the collection of high frequency ($\geq$ 10 kHz) sonar data in shallow water ($\leq$ 100 m) was developed and used for experiment in Block Island Sound during September 1991. With the digital data recorded, high resolution acoustic images of spherical targets were subsequently formed; moreover, analysis of surface and bottom reverberation was made and correlated with environmental measurements.

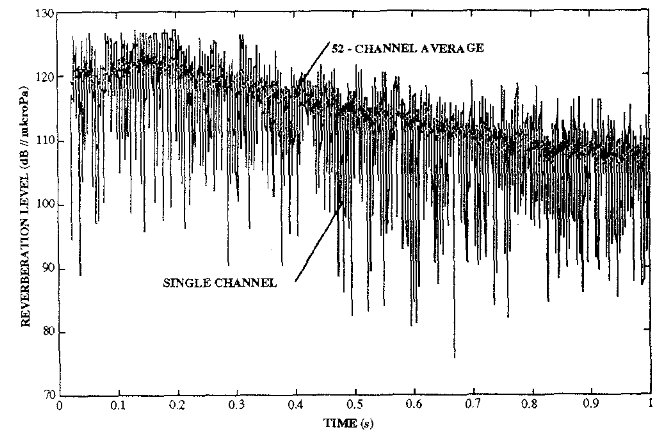
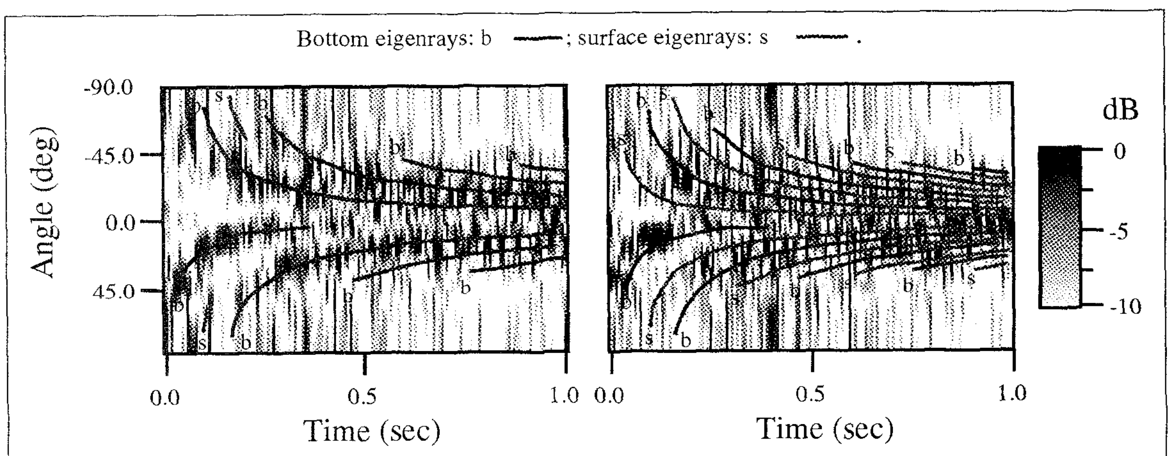


Fig. 9. Reverberation level vs time: spatial average over 52 channels compared with single channel.



Case (a): ssp(a); wind speed is 1.4 m/s. Case (b): ssp(b); wind speed is 4.1 m/s.

Fig. 10. Measured reverberation (logarithmic gray level within 10 dB of instantaneous maximum) vs. vertical angle and time for two cases. Eigenrays calculated from GSM [2].

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