Panama City 2003 Broadband Shallow-water Acoustic Coherence Experiments

Steve Stanic[*], Edgar Kennedy[*], Dexter Malley[*], Bob Brown[*], Roger Meredith[*], Robert Fisher[*], Howard Chandler[*], Richard Ray[**], and Ralph Goodman***

**Code 7184, Naval Research Laboratory, Stennis Space Center, Ms. 39529*
*** Code 7330, Naval Research Laboratory, Stennis Space Center, Ms. 39529*
**** Department of Marine Sciences, University of Southern Mississippi*
Stennis Space Center, Ms 39529

Abstract. In June 2003 a series of acoustic propagation experiments were conducted off the coast of Panama City, Florida. The experiments were designed to measure and provide an understand of signal phase and amplitude fluctuations, and signal spatial and temporal coherence over several large horizontal and vertical arrays. The propagation measurements were conducted in a water depth of 8.8m and at ranges of 70 m and 150 m. The acoustic measurements cover frequencies from 1 to 140 kHz. The propagation measurements were supported by data obtained by wave rider buoys, CTD's, thermister chains and current meters. Bottom penetration data was also obtained using a buried hydrophone array. The experiments will be outlined and the data sets described.

INTRODUCTION

Measurements of acoustic signal fluctuations caused by random medium inhomogeneities have been made by numerous investigators and several papers have extensive bibliographies [1-7]. However, only a few measurements have been made in very-shallow-waters [6-11]. Since 1998, The Naval Research Laboratory's (NRL) high-frequency program has focused on understanding very-shallow-water high-frequency acoustic signal fluctuations caused by random medium inhomogeneities. The results of these measurements were shown to correlate acoustic signal phase variability with small-scale water column thermal variability and ocean swell conditions [12]. In June 2003, another series of shallow-water broadband propagation measurements were conducted. The objectives of these experiments were to measure and understand broadband horizontal and vertical signal coherence over large vertical and horizontal array apertures, and to measure and understand acoustic penetration into the sediment at sub-critical grazing angles. These measurements were conducted over a broad range of frequencies and changing oceanographic conditions. In addition, to minimize the effects of the ocean's swell, the experiment was configured so that the acoustic propagation path was always parallel to the shore line.

This paper will describe the experimental layout and types of measurements taken. We will seek to understand the acoustic measurements in terms of the environmental conditions. The analysis of these data is just beginning, and at this time only a limited attempt is made to model the acoustic results. In the papers that follow, only a few preliminary acoustic measurement results will be presented. Detailed analysis and modeling of the data will be the subject of future publications. For these proceedings, several papers will be presented describing the data acquisition and environmental measurement systems. A description of the oceanographic conditions during the experiments and initial coherence and buried hydrophone results will be presented.

EXPERIMENTAL CONFIGURATION

The experiments took place in a 300 m by 300 m area just off the beach in Panama City, Florida (Fig. 1). The area has several offshore sand bars, one very close the beach and the other about 100 m from the shore line. The measurements took place 545 m from the shore line in a water depth of 8.8 m. The ocean sediments in this area are generally a mixture of medium sand and shell hash with the occasional large shell fragment.

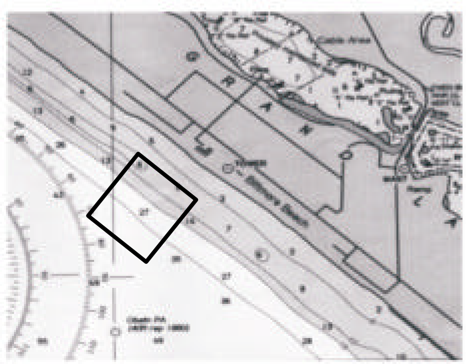

FIGURE 1. Experimental location

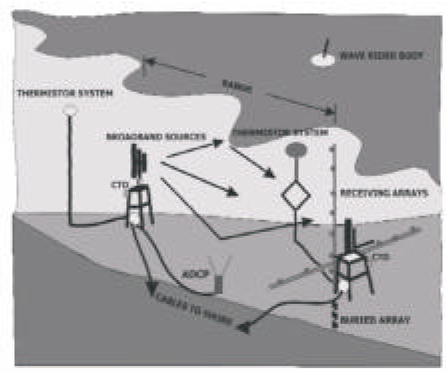

FIGURE 2. Schematic of experimental setup

A schematic of the experimental layout is shown in Fig. 2. Four broadband source arrays were mounted on a 3-axis positioning system that was mounted on one of NRL's shallow-water towers. The high-frequency source arrays covered a frequency range from 18 kHz to 200 kHz. The arrays were designed to have very narrow vertical beamwidths that ranged from 2^0 (-3dB) at 18 kHz to less than 1^0 (-3dB) at 200 kHz. Horizontal beamwidths ranged from 58^0 (-3dB) at 18 kHz to 44^0 (-3dB) at 200 kHz. The maximum response axis (MRA) of these sources was 4.1 m above the bottom. These narrow vertical beamwidths assured that there would be no boundary interactions over the propagation ranges used (70 m and 150 m). The low-frequency source array (1 kHz to 10 kHz) was a G34 supplied by the Naval Undersea Warfare Center Newport RI. This source was mounted 2.7 m above the bottom and had almost omni-directional beam patterns over the frequency range used.

The receiving arrays consisted of a 6 m vertical array and a 12 m horizontal array. The vertical array had ten equally spaced hydrophones while the horizontal array had seven unequally spaced hydrophones and was mounted 1.75 m above the ocean sediment. Both arrays were rigidly mounted to one of the small towers (Fig. 2). The data from these arrays were used to measure both the vertical and horizontal coherence of the low-frequency multi path signals. These array configurations and hydrophone spacings are shown in Fig. 3.

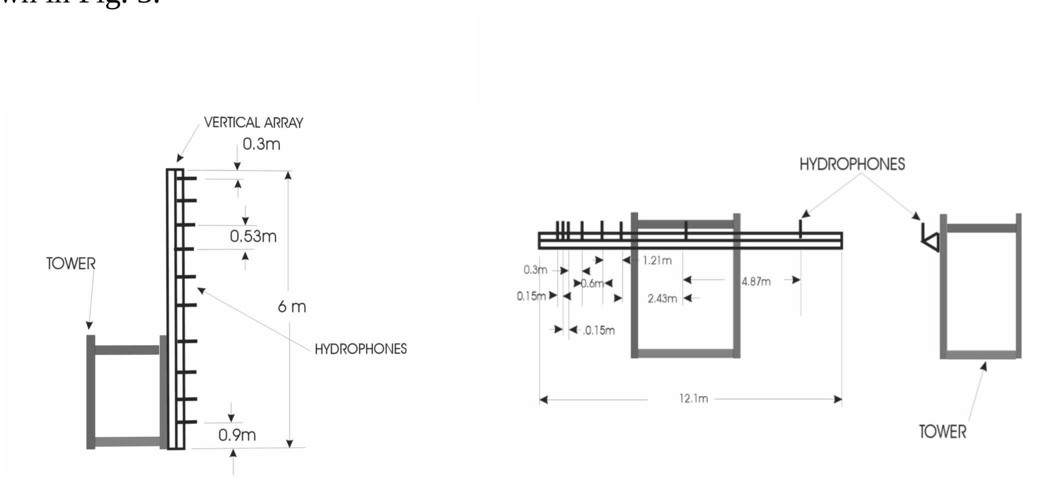

FIGURE 3. Low-frequency vertical and horizontal array configurations

Also mounted on the receive tower were several vertical high-resolution high-frequency receiving arrays with beam patterns similar to those of the high-frequency source arrays. These arrays were used the measure high-frequency temporal phase variability caused by only the random medium inhomogeneities in the ocean's water column. A small 1 m long by 1 m high high-frequency receiving array was also mounted on the receive tower. This array had 6 hydrophones mounted on both the vertical and horizontal arms. These high-frequency hydrophone array configurations are shown in Fig. 4. These arrays are also mounted on a three axis positioning system. Fig. 5 are photographs of the assembled transmit and receive system.

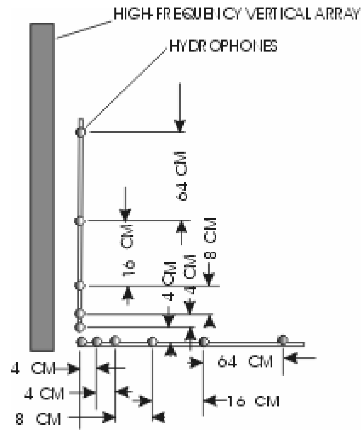

FIGURE 4. High-frequency receive arrays

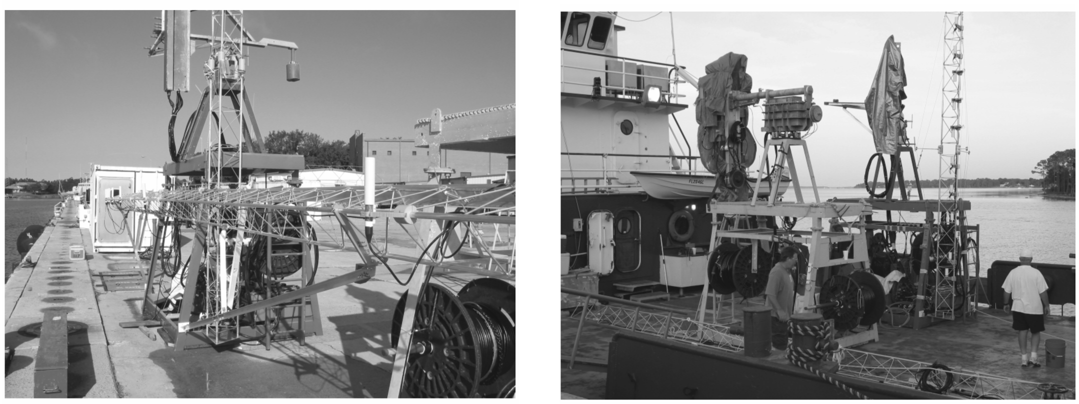

FIGURE 5. Shallow-water array systems

A six-element, 0.5 m long hydrophone array was water jetted into the sediment at the foot of the vertical array and was used to measure the energy propagating into the sandy bottom at sub critical grazing angles.

Data from all the receiving array systems were wired into electronic canisters located at the base of each tower. The data was then multiplexed on to fiber optic cables and send to an instrumentation van located on the beach. Here the signals were filtered, amplified, digitized at 1 MHz and recorded. Each acoustic measurement sequence consisted of 500 to 1,000 pings with a repetition rate of 1 Hz.

ENVIRONMENTAL MEASUREMENTS

Obtaining an accurate characterization of an oceanographic environment is a difficult task. In order to understand acoustic propagation and signal coherence measurements a number of environmental measurements systems were designed and deployed to measure the important water column properties and their fluctuations. A complete description of the sensor systems and descriptions of the general environmental conditions are given in a following paper.

Figure 6 shows the placement of the environmental sensor systems. Two high-resolution thermistor systems (FRTS and TMMS) were deployed along the propagation path. The vertical system (FRTS) which was connected to the source tower canister, had 9 thermistors that covered the entire water column. The second thermistor system (TMMS) was deployed at the height of the MRA of the high-frequency source arrays and measured the small scale spatial and temporal thermal variations over a 1 m square area. The output from both systems was cabled back to the instrumentation van and displayed in real time.

An RDI ADCP system was deployed close to the receive tower in an upward looking configuration. The output of the ADCP was also cabled back to the shore station and displayed in real time. To measure the near bottom currents, an S4 current meter was mounted on a 1 m high frame and deployed near the ADCP.

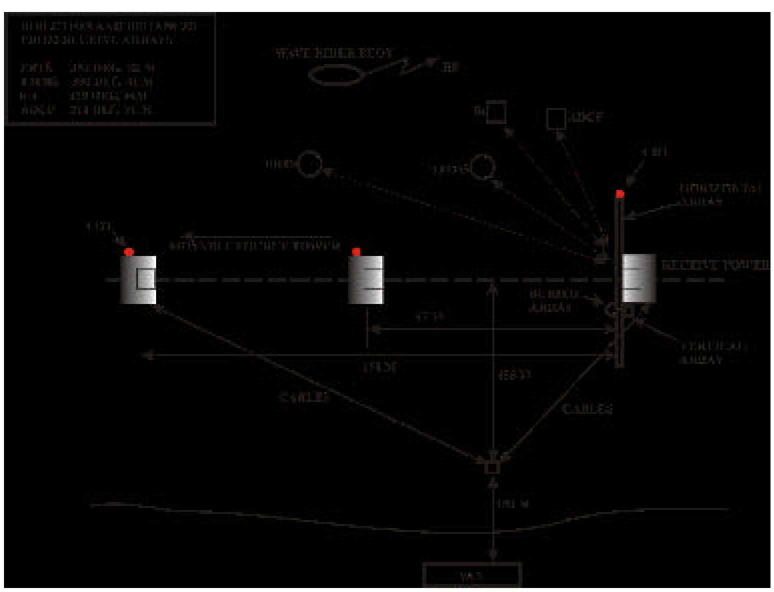

FIGURE 6. Placement of acoustic and environmental sensor systems

A Sea bird model 49 FastCAT CTD was mounted on each tower. These systems measured the temperature and salinity time series. The outputs of each were also displayed on monitors in the shore station.

A Neptune Sciences wave rider buoy was deployed south of the center of the propagation path. It provided a 17-minute average of the wave directional spectra each hour. A weather station measured wind vectors, atmospheric temperature, and humidity.

ACOUSTIC MEASUREMENTS

The acoustic propagation measurements were taken first at a range of 70 m. The source tower was then moved out to a range of 150 m and additional propagation measurements taken. At each range, propagation measurements were taken over a wide range of environmental conditions and frequencies. These ranged from days with very light winds, days with stable water columns, and days when the wind velocities reached 35 to 40 knots. Measurements were also taken during times when the water column thermal variabilities approached 1.0 ^{0} C. Table I is a listing of the transmitted signals and their characteristics.

TABLE 1. Transmitted signal characteristics

Range (m)	Source	Pulse type	Frequencies (kHz)	Pulse Length (ms)
70	G34	Broadband	1 to 10 kHz	4
	HF1	CW	18,20,22,24	1
150	HF2	CW	40,60,80	1
	HF3	CW	100,120,140	1

Low-frequency propagation measurements were taken using the G34 at both the 70 m and 150 m ranges. A broadband pulse (Fig. 7) was transmitted and the signal forward scattering from the ocean surface and bottom received on the large aperture horizontal and vertical arrays.

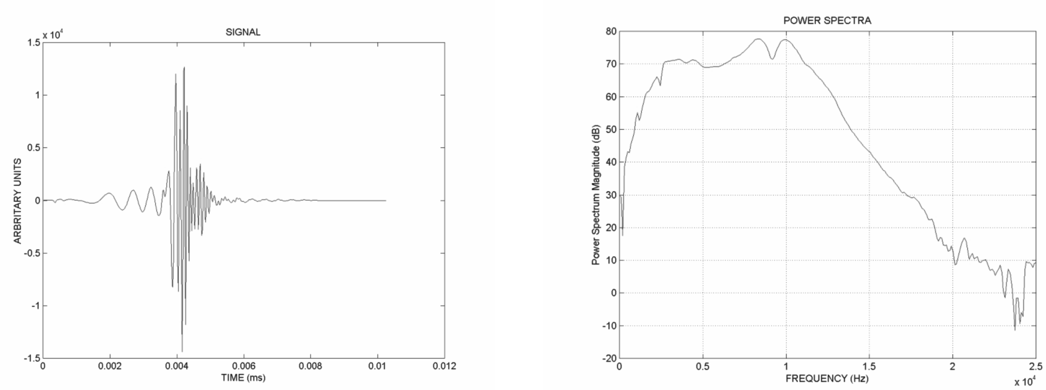

FIGURE 7. Low-frequency broadband pulse and spectra

Figure 8 shows a time history of several signals envelopes received on one of the horizontal array channels on a very calm day. It is clear that the beginning signal is stable for the first direct path arrival. The rest of the signal is dominated by the multi path arrivals from the surface and bottom. These data are being analyzed to calculate horizontal and vertical coherence as a function of frequency, hydrophone separation, range, and time.

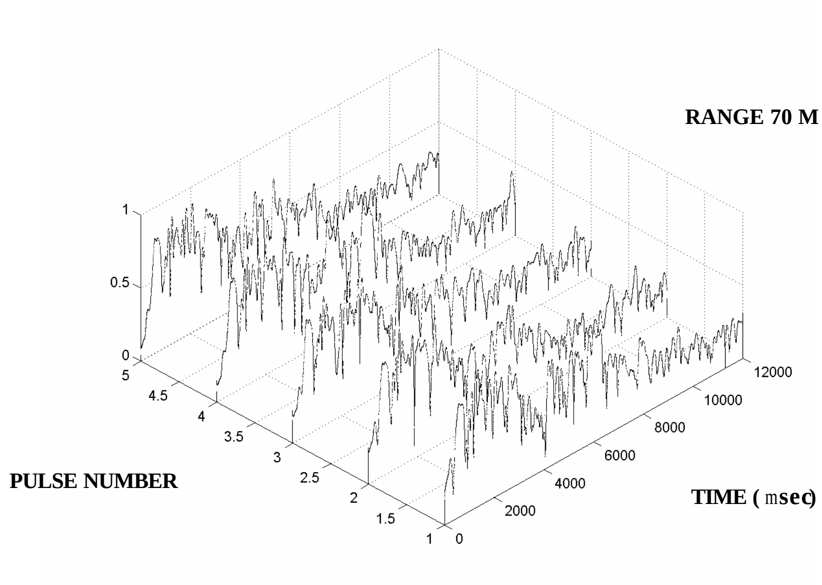

FIGURE 8. Broadband signals received on one of the horizontal array channels

The buried hydrophone array measured the levels of these low-frequency signals as they propagated into the sediment at angles below critical. The data will be used to determine acoustic attenuation, and the penetration ratios. OASES [13] will be used to model the penetration and identify the penetration mechanisms.

High-frequency propagation measurements were taken using the narrow beam width vertical source and receiving arrays. Figure 9 is an example of the high-frequency signal envelopes from one of the array channels. A 1 ms long CW was transmitted. Because of these very narrow vertical beamwidths, the measured signal fluctuations were due only to the randomness in the water column. The received signals clearly show no evidence of multipath interference.

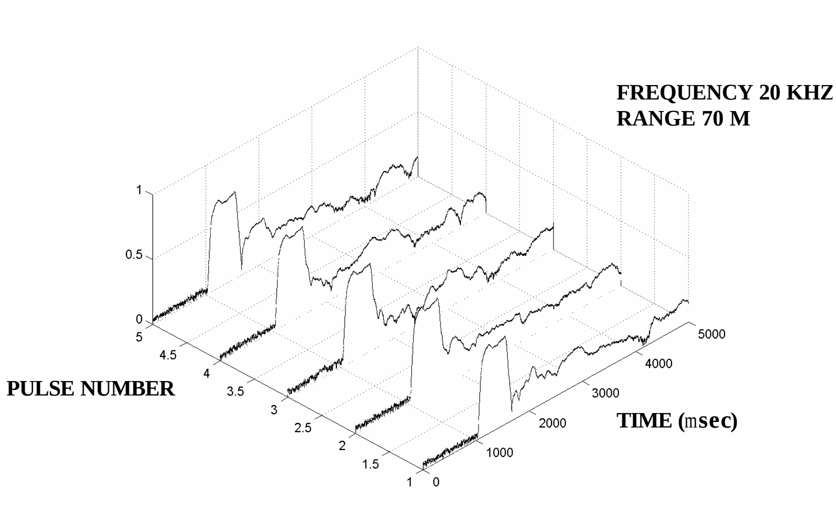

FIGURE 9. Received direct path high-frequency CW pulse

Signal fluctuation statistics will be calculated and correlated with thermal variabilities measured by the thermistor systems. At the same time the small vertical and horizontal high-frequency arrays will measure the high-frequency signal correlations as a function of frequency, range, and hydrophone spacing.

SUMMARY

A shallow-water coherence experiment was conducted during the summer of 2003. The experiments were designed to measure and understand broadband spatial and temporal coherence as a function of propagation range, frequencies, hydrophone separation, and changing oceanographic parameters. The important environmental parameters and their fluctuations which are important to modeling and understanding the coherence measurements were also measured.

ACKNOWLEDGMENTS

This work was supported by the Office of Naval Research, technical management by the Naval Research Laboratory under program element 62435N.

REFERENCES

1. R. M. Kennedy, "Phase and Amplitude Fluctuations in Propagating Through a Layered Ocean," J. Acoust. Soc. Am., vo.l 46, pp-737-745, 1969.

2. D.C. Whitmarsh, E. Skudrzyk, and R. J. Urick, "Forward Scattering of Sound in the Sea and its Correlation with Temperature Microstructure", J. Acoust. Soc. Amer. Vol. 29, p. 1124, (1957).
3. R. F. Shvachko, "Sound Fluctuations in the Upper Layer of the Ocean and their Relation to the Random Inhomogeneities of the Medium", Soviet Physics-Acoustics, Vol. 9, p. 280, (1964).
4. 2 . H. Medwin, "Sound Phase and Amplitude Fluctuations due to Temperature Microstructure in the Upper Ocean," J. Acoust. Soc. Am., vol 56, pp 1105-1110, 1974.
5. 3 . T. Ewart, "Acoustic Fluctuations in the Open Ocean-A Measurement using a fixed Refracted Path," J. Acoust. Soc. Am., vol 60, pp 46-59, 1976.
6. 4 . D. M. Farmer, S. F. Clifford, and J. A. Verrall, "Scintillation of a Turbulent Tidal Flow," J. Geophysical Research, vol 92 pp 5369-5382, 1987.
7. 5. B. J. Uscinski, "Broadband Acoustic Transmission Intensity Fluctuations in the Tyrrhenian Sea," J. Acoustic. Soc. Am., vol 100, pp 784-796, 1996.
8. 6 . P. T. Gough and M. P. Hayes, "Measurements of Acoustic Phase Stability in Loch Linnhe, Scotland," J. Acoustic. Soc. Am., vol 86, pp 837-839, 1989.
9. 7 . J. T. Christoff, C. D. Loggins, and E. L. Pipkin, "Measurements of the Temporal Phase Stability of the Medium," J. Acoust. Soc. Am., vol 71, pp 1606-1607, 1982.
10. 8 . S. Guyonic, " Experiments on a Sonar with a Synthetic Aperture Array Moving on a Rail," Proceedings of the IEEE Ocean 94, vol III, pp 571-576, 13-16 Sept., 1994.
11. 9 . O. Bergem, N. G. Pace, and D Di Iorio, "Surface Wave Influence on Acoustic Propagation in very Shallow-Water," Proceeding of the MTS/IEEE Oceans 99, vol 1, 13-6 Sept., 1999.
12. 10. S. J. Stanic, R. R. Goodman, R. W. Meredith, and E. Kenedy, ‘ Measurement of High-Frequency Shallow-Water Acoustic Phase Fluctuations,” IEEE J. of Oceanic Engineering, vol 25, No. 4, pp 507-515, 2000.
13. 11. H. Schmit, “OASES Version 2.2 Users Guide and Reference Manual,” Massachusetts Instsitite of Technology, Cambridge, MA. 1999.