

MURI: Impact of Oceanographic Variability on Acoustic Communications

W.S. Hodgkiss
Marine Physical Laboratory
Scripps Institution of Oceanography
La Jolla, CA 92093-0701
phone: (858) 534-1798 / fax: (858) 822-0665
email: whodgkiss@ucsd.edu

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<http://www.mpl.ucsd.edu>

LONG-TERM GOALS

Couple together analytical and numerical modeling of oceanographic and surface wave processes, acoustic propagation modeling, statistical descriptions of the waveguide impulse response between multiple sources and receivers, and the design and performance characterization of underwater acoustic digital data communication systems in shallow water.

OBJECTIVES

Develop analytical/numerical models, validated with experimental data, that relate short-term oceanographic variability and source/receiver motion to fluctuations in the waveguide acoustic impulse response between multiple sources and receivers and ultimately to the capacities of these channels along with space-time coding and adaptive modulation/demodulation algorithms that approach these capacities.

APPROACH

The focus of this research is on how to incorporate an understanding of short-term variability in the oceanographic environment and source/receiver motion into the design and performance characterization of underwater acoustic, diversity-exploiting, digital data communication systems. The underlying physics must relate the impact of a fluctuating oceanographic environment and source/receiver motion to fluctuations in the waveguide acoustic impulse response between multiple sources and receivers and ultimately to the channel capacity and the design and performance characterization of underwater acoustic digital data communication systems in shallow water. Our approach consists of the following thrusts.

1. Modeling short-term variability in the oceanographic environment.

The long-term (beyond scales of minutes) evolution of the physical oceanographic environment (e.g. due to currents and long period internal waves) imparts slow changes to the waveguide acoustic propagation characteristics. In contrast, surface waves driven by local winds and distant storms exhibit dynamics on much shorter scales (seconds to tens of seconds) and directly impact short-term acoustic fluctuations. In addition, shorter-period internal waves, finestructure, and turbulence also will contribute to propagation variability. An important question is the relative impact each of these has on short-term acoustic fluctuations. Here we will couple models of the background time-evolving

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oceanographic environment with models of the surface wave dynamics to provide realistic sound speed fields along with their spatiotemporal correlation structure.

2. Transformation of environmental fluctuations and source/receiver motion into waveguide acoustic impulse response fluctuations between multiple sources and receivers.

Both ray-based (Sonar Simulation Toolset and Bellhop) and full-wave (Parabolic Equation) propagation modeling methods will be used to transform simulated sound speed fields, surface wave dynamics, and source/receiver motion directly into dynamic acoustic pressure fields. A Monte Carlo approach will be used to simulate realistic time-varying impulse responses between multiple sources and receivers. As an alternative, adjoint methods quantify the sensitivity of the channel impulse response to oceanographic (and geometric) variability. The linear approximation inherent in the sensitivity kernel may be valid for only a limited dynamic range of the environmental fluctuations corresponding to just a few seconds at the frequencies of interest but might provide useful insight into the mapping between environmental and acoustic fluctuations and subsequently to estimating the environmentally-dependent acoustic channel capacity.

3. Spatiotemporal statistical descriptions of waveguide impulse response fluctuations.

Statistical descriptions summarizing the spatiotemporal relatedness of waveguide impulse response fluctuations provide insight into the influence of environmental dynamics and can be used for system design and performance evaluation purposes. The scattering function provides a useful description of the channel in time delay and Doppler. In addition to estimating the scattering function from ensembles of realizations of fluctuating impulse responses (either from realistic simulations or at-sea observations), we also will use the sensitivity kernel for the impulse response combined with the dynamics and statistics of the environmental fluctuations to estimate the scattering function.

4. Channel capacity and the design and performance characterization of underwater acoustic, diversity-exploiting, digital data communication systems.

Channel capacity sets an upper bound on the information rate that can be transmitted through a given channel. The capacity of the highly dispersive and fluctuating ocean environment cannot be derived in closed form but only simulated or derived from measurements. In addition, realistic (constrained) capacity bounds will be derived that include practical implementation issues such as those imposed by phase-coherent constellations and realizable equalization schemes. Based on multiple source and receiver channel models developed from measured waveguide characteristics, we will assess the capacity of underwater acoustic channels and these will serve as goals for the design of space-time coding techniques and adaptive modulation/demodulation algorithms. An especially challenging problem in multipath-rich waveguides is the design of coherent communication schemes between moving platforms.

5. Benchmark simulations and validating experimental data.

A set of benchmark simulation cases will be defined for use in exploring transmitter/receiver design and performance characterization in the deployment of diversity-exploiting digital data telemetry systems (point-to-point and networked). Both fixed-fixed (stationary) and moving source and/or receiver scenarios will be considered across bands of frequencies in the range 1-50 kHz. Multiple source and receiver cases (MIMO) will be of particular interest. Validating experimental data will be

obtained during the ONR acoustic communications experiment in summer 2008 and other follow-on experiments to be scheduled in the future.

To address the issue of underwater acoustic digital data communication in a fluctuating environment, we have brought together a multidisciplinary research team consisting of oceanographers, ocean acousticians, and signal processors. Team members consist of faculty and researchers from four universities and unfunded collaborators from private industry and a navy laboratory:

- University of California, San Diego (UCSD) - W.S. Hodgkiss, W.A. Kuperman, H.C. Song, B.D. Cornuelle, and J.G. Proakis
- University of Washington (UW) - D. Rouseff and W. Fox
- University of Delaware (UDel) - M. Badiey and J. Kirby
- Arizona State University (ASU) - T. Duman
- Heat, Light, and Sound (HLS) - M. Porter, P. Hursky, and M. Siderius
- SPAWAR Systems Center – San Diego (SSC-SD) – V.K. McDonald

WORK COMPLETED

This is a new MURI begun mid-FY07. In addition to discussions within the group related to the thrusts outlined above, planning also is taking place for the ONR acoustic communications experiment to take place in summer 2008.

RESULTS

Recent analysis of experiment data from the ONR 2003 KauaiEx experiment is illustrative of the issues being addressed in this MURI [1]. Fig. 1 shows the waveguide environment. KauaiEx was conducted west of Kauai, HI, in 100 m deep water. An autonomous acoustic source was deployed 5 m above the seafloor. For the data discussed here, a 75 m aperture, 16-element autonomous vertical receiving array was deployed approximately 3 km from the source. In this downward-refracting environment, much of the received energy is concentrated at the lower array elements while the upper array elements are less well-insonified.

Examples of the short-term fluctuations in the observed channel impulse response (CIR) are provided in Figs. 2 and 3. These both correspond to a 10 s duration time interval (vertical axis) with the CIR delay spread being on the order of a few tens of ms (horizontal axis). Fig. 2 corresponds to a receiving element at 36.5 m depth and Fig. 3 to a receiving element at 86.5 m depth. The upper elements have a longer duration CIR that fluctuates rapidly while the deeper elements have a shorter duration CIR which appears to be more stable although still varying over the observation interval.

IMPACT / APPLICATIONS

Acoustic data communications is of broad interest for the retrieval of environmental data from in situ sensors, the exchange of data and control information between AUVs (autonomous undersea vehicles) and other off-board/distributed sensing systems and relay nodes (e.g. surface buoys), and submarine communications.

RELATED PROJECTS

In addition to other ONR Code 321OA and Code 321US projects investigating various aspects of acoustic data communications from both an ocean acoustics and signal processing perspective, a second MURI also is focused on acoustic communications (J. Preisig, “Underwater Acoustic Propagation and Communications: A Coupled Research Program”).

PUBLICATIONS

[1] A. Song, M. Badiey, H.C. Song, W.S. Hodgkiss, and M.B. Porter, “Impact of ocean variability on coherent underwater acoustic communications during KauaiEx,” J. Acoust. Soc. Am. (submitted, 2007).

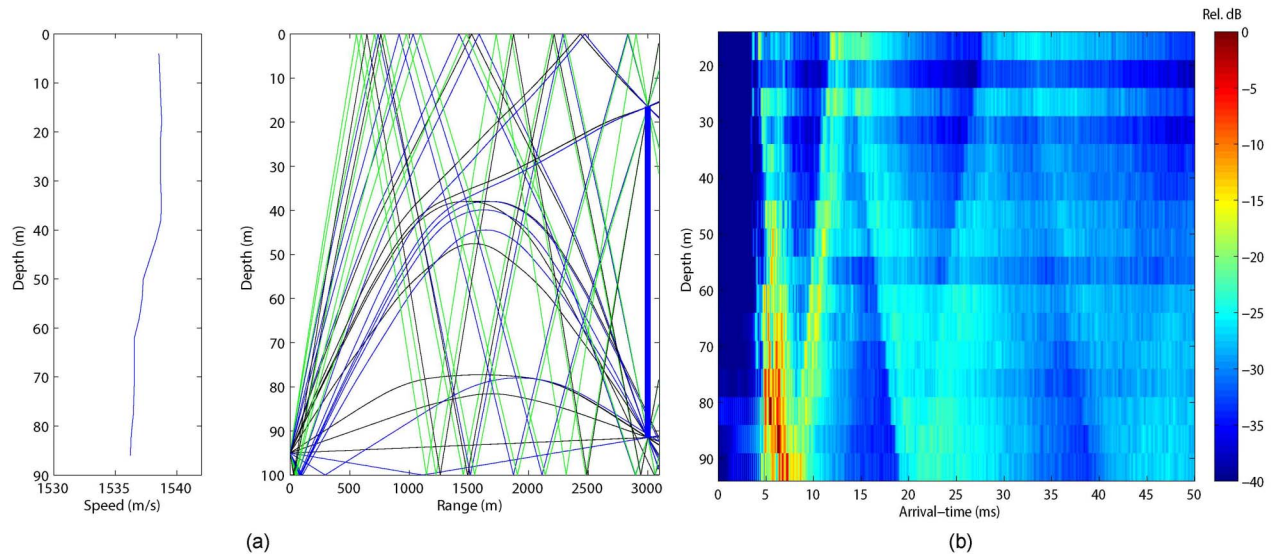


Figure 1. Sound speed profile measured during the communications transmissions, corresponding ray trace along with an indication of the placement of the vertical array in the water column, and full water column transmission loss.

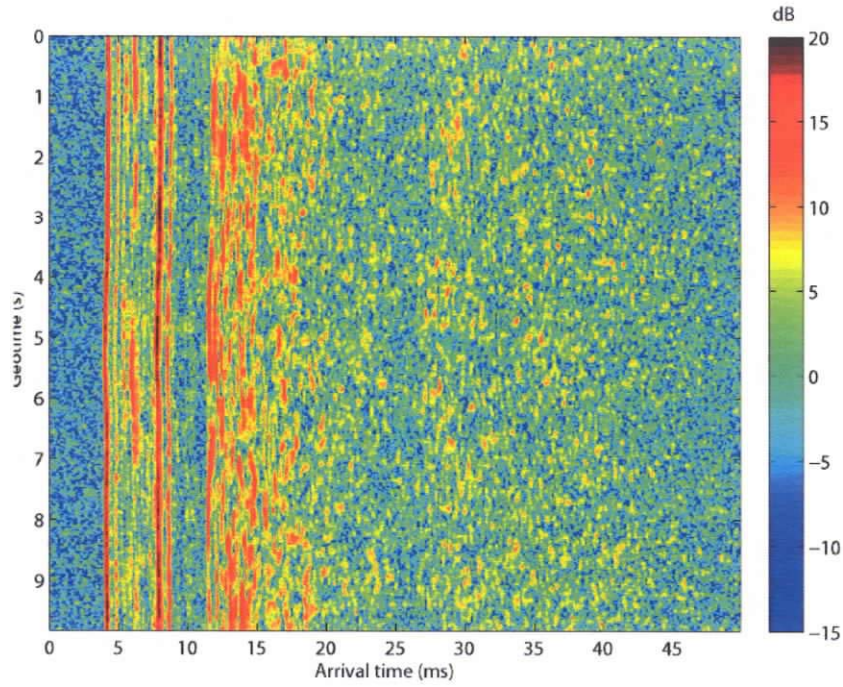


Figure 2. Short-term fluctuations in the channel impulse response (CIR) over 10 s (vertical axis) at 36.5 m receiving hydrophone depth.

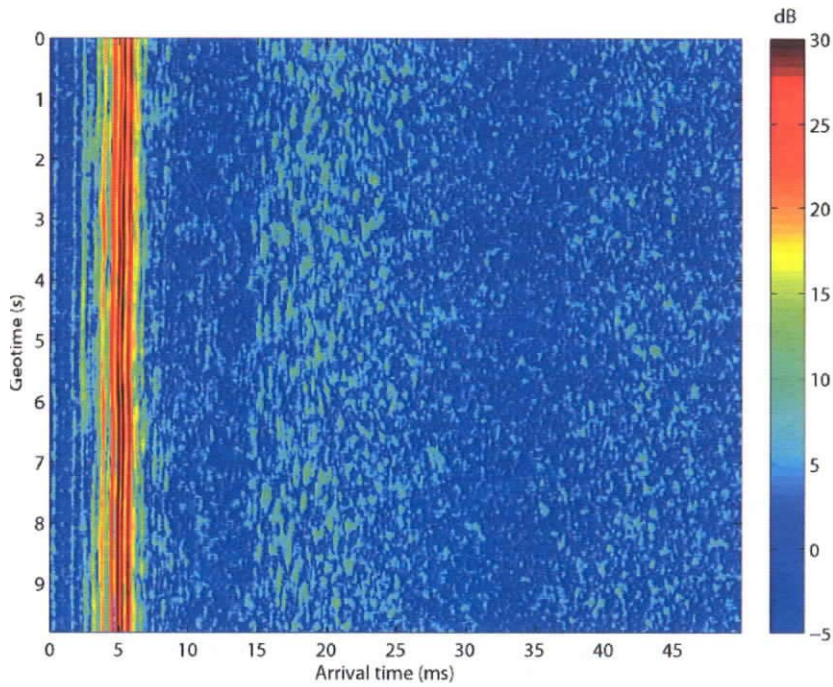


Figure 3. Short-term fluctuations in the channel impulse response (CIR) over 10 s (vertical axis) at 86.5 m receiving hydrophone depth.