Propagation and Scattering in a Variable Shallow Water Waveguide

Daniel Rouseff
Applied Physics Laboratory
University of Washington
1013 NE 40th St.
Seattle, WA 98105
phone: (206) 685-3078 fax: (206) 543-6785 email: rouseff@apl.washington.edu

Grant Number: N00014-1010495
http://www.apl.washington.edu

LONG-TERM GOALS

Random variability in shallow water will induce variability in a propagating acoustic field. The long-term goal of this research is to quantify how random variability in the ocean environment translates into random variability in the acoustic field and the associated signal processing algorithms propagation in the mid-frequency (1-10 kHz) band. In the present funding cycle, the emphasis is on acoustic scintillation and the waveguide invariant.

OBJECTIVES

The first objective for the current funding cycle is to quantify acoustic scintillation in the mid-frequency regime due to the linear background internal wave field. The second objective is to extend usage of the waveguide invariant concept to the mid-frequency regime, particularly for active sonar scenarios. The long-term objective is to merge these two research strands and quantify how random variability in the water column limits the usefulness of the waveguide invariant concept at mid frequencies.

APPROACH

Our approach is a mixture of data analysis, theoretical development, and modeling. For the acoustic scintillation work, we use acoustic and environmental data collected during the Shallow Water 2006 Experiment (SW06).[1] These experimental observations guide the development of models. This work is done in close collaboration with other SW06 participants especially Dajun Tang, Jie Yang, and Frank Henyey. For the waveguide invariant work, we collaborate with investigators from the Naval Research Laboratory[2] and Lisa Zurk of Portland State University.

WORK COMPLETED

Single-path acoustic intensity fluctuations were examined using mid-frequency (1-10 kHz) data collected during the Shallow Water 2006 (SW06) experiment. The data were collected over several hours at a fixed range of 1 km. A specific path that went through two upper turning points separated by a single bottom bounce was isolated. The path is ideal for the present purpose of isolating intensity fluctuations that are presumably due to water column variability. The path does not reflect off the sea surface and so is uncontaminated by surface waves. The path has two turning points in the thermocline. This is important because, loosely speaking, the sound speed perturbations due to linear internal waves scale like the gradient of the background sound speed profile. Consequently, the path of interest turns twice in the region of strongest internal wave activity. The frequency-dependent scintillation index, related to the fourth moment of acoustic pressure, was then estimated for the isolated path.

With respect to the mid-frequency waveguide invariant effort, a bistatic active sonar scenario was considered. A broadband signal scattered from a point target at range r with the resulting scattered field recorded on a horizontal aperture y. Let the bearing of the target be ϕ relative to the aperture. The level of curves of intensity in aperture y and frequency ω space were shown to satisfy:

$$\frac{d\omega}{dy} = -\beta \frac{\omega}{r \sin\phi} + \text{(additional terms)}$$

where β is the waveguide invariant.[3] To the extent that the "additional terms" can be neglected, the result is similar to what is observed with passive sonar.

RESULTS

The single-path scintillation index (SI) was evaluated over the mid-frequency regime. At 2 kHz, the SI was small. Between 2 and 5 kHz, the SI increases approximately linearly with frequency. At 6 kHz, the scintillation index is greater than one (SI = 1.2) indicating strong focusing and supersaturated conditions. The SI then gradually decreases with SI = 1.0 at 9.5 kHz indicating saturation. The has the classic behavior predicted by heuristic arguments that focusing and defocusing causes scintillation. The surprising result is that this complete transition—from unsaturated to strong focusing to saturation—is observed at such short range (1 km) as the frequency advances through the mid-frequency (1-10 kHz) band.

With respect to the mid-frequency waveguide invariant effort, Figure 1 shows the result of a numerical simulation for the bistatic active sonar problem. Shown is acoustic intensity mapped as a function of frequency and position along the receiving array. Striations are clearly evident and consistent with the expected value for the waveguide invariant. The result suggests that the "additional terms" in the above equation can be neglected.

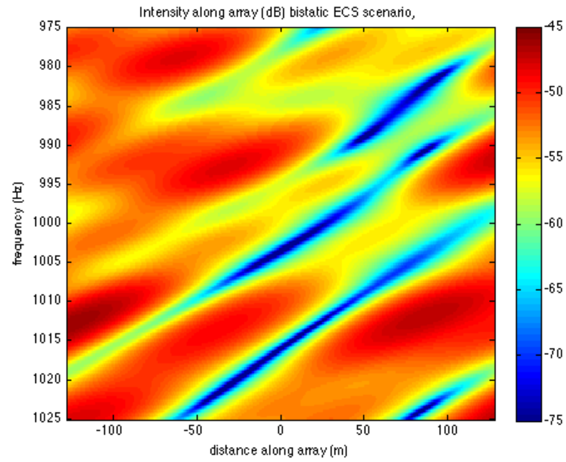

Figure 1. Intensity striation patterns in at mid-frequencies for bistatic active sonar scenario.

IMPACT/APPLICATIONS

Internal waves are a ubiquitous feature of shallow water oceanography. Even when event-like non-linear internal waves are absent, random background internal waves will affect acoustic propagation in the mid-frequency regime relevant to Navy sonar systems.

The SW06 data analysis result shows the scintillation index transitioning from weak scattering to strong focusing to saturation. This experimental result is significant from an operational standpoint because acoustic scintillation limits temporal and spatial coherence and can affect one's ability to detect and track targets of interest. Remote geoacoustic inversion would also be hampered; effects due to the water column might falsely be attributed to seabed variability.

RELATED PROJECTS

Numerous ONR-supported investigators were involved in the SW06 Experiment and are analyzing the collected data.

REFERENCES

[1]D. Tang, J. N. Moum, J. F. Lynch, P. Abbot, R. Chapman, P. H. Dahl, T. F. Duda, G. Gawarkiewicz, S. Glenn, J. A. Goff, H. Graber, J. Kemp, A. Maffei, J. D. Nash, and A. Newhall, "Shallow Water '06, A Joint Acoustic Propagation/Nonlinear Internal Wave Physics Experiment," *Oceanogr.* 20, 156-167, 2007.

[2]A. Turgut, M. Orr, and D. Rouseff, "Broadband source localization using horizontal-beam acoustic intensity striations," *J. Acoust. Soc. Am.* 127, 73-83 (2010).

[3]L. M. Brekhovskikh and Y. P. Lysanov, Fundamentals of Ocean Acoustics, 2nd ed. (Springer-Verlag, New York, 1991).

PUBLICATIONS

D. Rouseff and D. Tang, “Internal waves as a proposed mechanism for increasing ambient noise in an increasingly acidic ocean,” *J. Acoust. Soc. Am.* 127, EL235-EL239 (2010) [published, refereed].

J. Yang, D. Rouseff, D. Tang, and F. S. Henyey, “Effect of the internal tide on acoustic transmission loss at mid-frequencies,” *IEEE J. Oceanic Eng.* 35, 3 – 11 (2010) [published, refereed].

A. Turgut, M. Orr, and D. Rouseff, “Broadband source localization using horizontal-beam acoustic intensity striations,” *J. Acoust. Soc. Am.* 127, 73-83 (2010) [published, refereed].

D. Rouseff, M. Badiey, and A. Song, “Effect of reflected and refracted signals on coherent underwater acoustic communication: Results from KauaiEx 2003.” *J. Acoust. Soc. Am.* 126, 2359-2366 (2009) [published, refereed].

D. Rouseff, Z. Wang, S. Zhou, and L. Zhou, “The 2009 Cooperative Array Performance Experiment (CAPEx09) comparing vector- and pressure-sensor arrays,” European Conference on Underwater Acoustics, Istanbul, Turkey July 5-9, 2010 [invited, non-refereed].
.